Science on a Deep-Ocean Shipwreck[1]

CHARLES E. HERDENDORF, Departments of Geological Sciences and Zoology, Museum of Biological Diversity, The Ohio State University, Columbus, OH 43212

THOMAS G. THOMPSON AND ROBERT D. EVANS, Columbus-America Discovery Group, 433 West Sixth Avenue, Columbus, OH 43201

ABSTRACT. A five-year scientific investigation of a site on the North Atlantic seafloor, 270 km off Cape Fear, NC, at a depth of 2,200 m, was undertaken in conjunction with recovery operations on a nineteenth-century steamship (SS *Central America* which sank in an 1857 hurricane while carrying passengers and cargo en route to New York from the California gold fields). Activities in the disciplines of oceanography, marine geology, marine biology, materials science, and undersea archaeology were undertaken with the tele-directed submersible robot, *Nemo*. The study included field observations at the site (recorded in over 3,000 hours of videotape and 25,000 still photographs), examination of hundreds of deep-ocean specimens and artifacts, and analysis of several experiments deployed on the seafloor. Resting on a gentle slope of the Blake Ridge, the shipwreck environment was cold, lightless, oxygen-rich, and flushed by moderate currents. The sediments were a foraminiferal-pteropod ooze, deposited at a slow rate (1.7 cm/1,000 years). A diverse community of errant and sessile benthic invertebrates and benthopelagic fishes colonized the shipwreck deriving from it food, cover, and a place of attachment. This deep-ocean oasis supported a greater variety and concentration of animal life than did the surrounding ooze habitat. The timbers of the shipwreck were degraded by wood-boring bivalves. The iron machinery was extensively corroded and mobilized into flow structures (rusticles) by iron-oxidizing bacteria. Passenger luggage recovered from the shipwreck contained artifacts which provided insight about the life styles of the voyagers during the Gold Rush. This project demonstrated that a holistic approach to a deep-ocean site of historic importance can provide understandings of the inter-related processes which affect cultural deposits on the abyssal seafloor and the marine life that they foster.

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INTRODUCTION

In the 1870s and 1880s, the U.S. Coast and Geodetic Survey mounted three expeditions with the steamer *Blake*. The purpose of these scientific ventures was to map and characterize the deep underwater features off the southeastern coast of the United States. Several prominent large-scale underwater landforms were discovered by researchers on these expeditions, and are named for this pioneering research vessel, i.e., Blake Plateau, Blake Ridge, and Blake Basin.

Biological trawls were an important component of the studies conducted aboard the *Blake* (Fig. 1). In 1888 when Dr. Alexander Agassiz reported on the results of these biological surveys he commented, "Deep-sea forms are almost always killed in the process of hauling, either by rough handling or else by the heat of the surface water." Resigned to his inability to see deep-sea animals where they live, he lamented, "We can scarcely hope ever to watch the habits of the deep-sea dwellers, and see them in their natural attitudes, and we must be content to imagine what these are by analogy with their shallow-water allies."

One hundred years later Dr. Agassiz's hope has been realized—scientists on board the research vessel *Arctic Discoverer* watched "the habits of the deep-sea dwellers" and saw the animals for the first time "in their natural attitudes." These observations were made possible with the use of the tele-directed submersible, *Nemo*, and color video transmission from a depth of 2,200 m on the Blake Ridge. Many creatures described in this paper were first described by Agassiz from samples taken on board the *Blake*.

The deep sea, at depths greater than 2,000 m, is known as the abyssal region of the ocean and is rarely viewed by scientists. Over 60% of the globe (~300 million km^2) is covered by seawater at least 2,000 m deep and, of all the water in the oceans, 74% lies below this depth. As vast as this region is, however, perhaps less than 1% of the deep sea has been explored by direct observation or even with the aid of remotely operated submersibles. The harshness of deep-sea environments and the high cost of abyssal expeditions are factors which have limited most explorations to brief, isolated ventures. The studies reported in the present paper are unusual for deep-ocean work in that they span a five-year period at a single location. Investigators were afforded the luxury of returning to the same location, the shipwreck of the SS *Central America*, for multiple dives each year (1987 to 1991), thereby developing a relatively long time-series of deep-sea observations in the North Atlantic Ocean.

The purpose of the present paper is to present a review of the findings of over 130 investigators who have participated in research projects dealing with the oceanography, marine geology, marine biology, materials science, and archaeology at the shipwreck site. The intent is not to provide detailed discussions and conclusions in these fields—that task remains for the specialists working on particular subject areas—although a great number of new observations are recorded here. Rather, the goal is to present an overview of a little-known but extensive oceanic environment by adding the results that have been obtained from the present studies to knowledge already recorded in the scientific literature.

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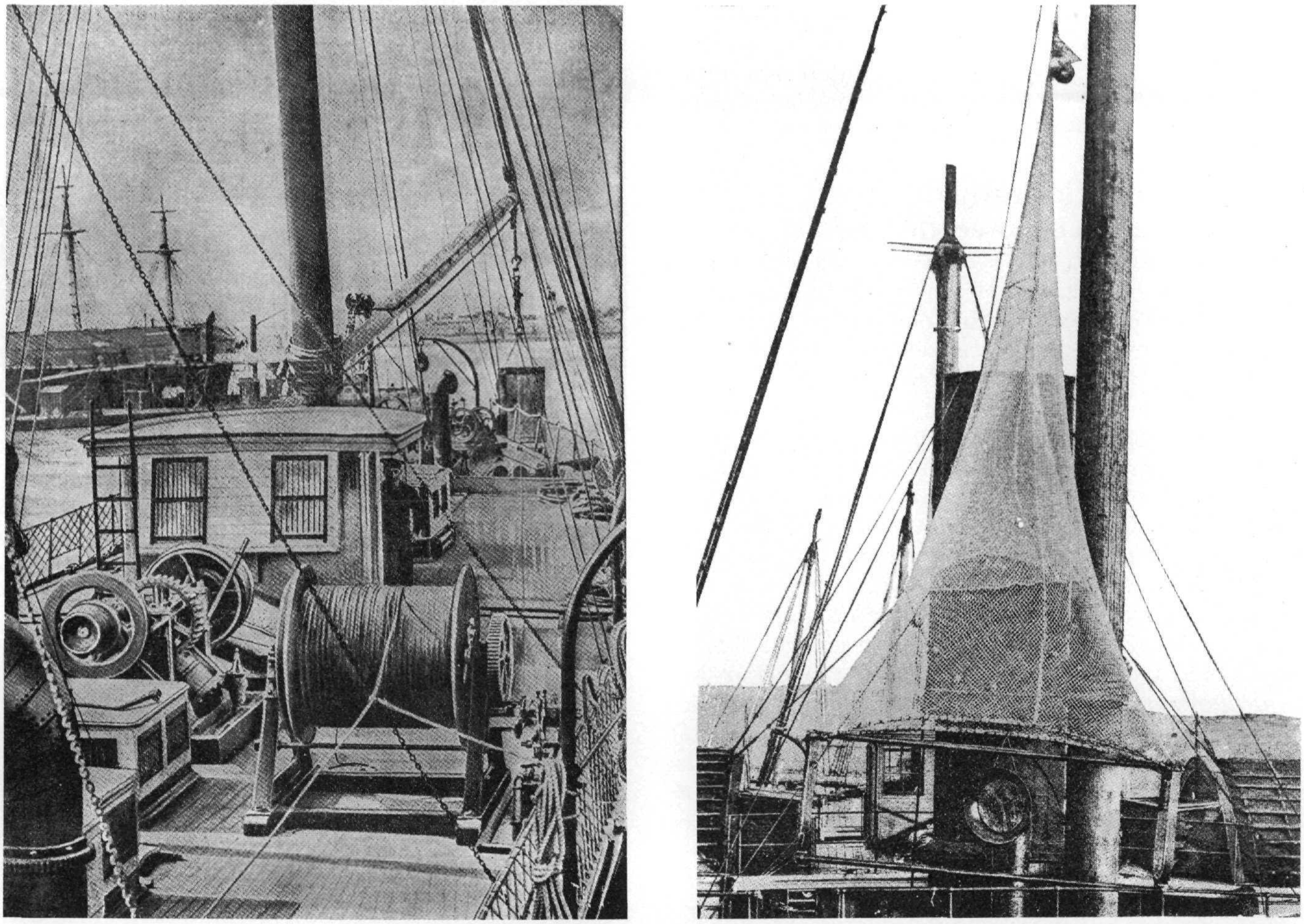

FIGURE 1. Deck of the U.S. Coast and Geodetic Survey steamer *Blake* showing the winding reel and engine (left) used to haul the trawl (right) from as deep as 3,500 m in the western North Atlantic Ocean in the 1870s and 1880s. The ship was under the command of Lt. Commander C. D. Sigsbee, USN and the scientific operations were directed by Dr. Alexander Agassiz. Deep-ocean casts made with trawl and dredge retrieved many of the same animals dead that were imaged living on the shipwreck of the SS *Central America*. Photographs reproduced from Agassiz (1888).

The middle of the last century was one of the most geographically dynamic periods in the history of the United States. America was a disjunct nation with well established cities on the eastern seaboard and frontier towns in California. When gold was discovered at Sutter's Mill near Sacramento in 1848, it precipitated the California Gold Rush and the country expanded westward at a rapid rate. Transportation links were sorely needed to meet the demands of the forty-niners and those who would follow in the next decade. While fortunes were made in the gold fields, the need for an efficient method of transporting goods to California and gold to eastern banks and other businesses stimulated the New York shipbuilding industry. In lower Manhattan, William H. Webb designed and constructed coastwise steamships and George W. Quintard built steam engines to service this need. The fate of one of these ships, the SS *Central America*, is one of the most fascinating stories in the annals of American maritime history, and is the focus of the present paper.

By the summer of 1857, the five-year-old SS *Central America* had successfully completed 43 round-trip passages on the Atlantic leg (New York to Panama) of the gold route to San Francisco. Known as the Panama Route, it connected the East and West coasts by two sets of steamers, one operating on the Atlantic and the other on the Pacific side of the Isthmus. But in mid-September of that year, the *Central America* steamed directly into the fury of a hurricane which had much the same track and destructive forces as Hurricane Hugo (September 1989). On this fateful 44th crossing she carried 476 passengers and 102 crew, as well as three tons of gold in a publicly reported commercial shipment, and an untold amount in passenger gold, all bound for New York from the California gold fields. After being battered by the storm for three days, the SS *Central America* sank with the loss of 425 lives and all of her cargo. The memory of this disaster was soon eclipsed by the greater tragedy of the Civil War, so that by the turn of the century the *Central America* was all but forgotten.

The remains of the ship rested on the deep-ocean floor for nearly 130 years. Then in the mid-1980s, a small team of engineers and scientists formed Columbus–America Discovery Group to locate and recover the ship's valuable cargo. In order to find the ship, years of historical research and tedious oceanographic surveys were undertaken by the Group. Once the *Central America* was located, new technologies were employed to construct a research submersible capable of performing complex and precision tasks at great ocean depths. From the project's inception, recovery operations included scientific exploration of marine life and the deep-ocean environment at the shipwreck site.

SS *CENTRAL AMERICA* PROJECT

Columbus-America Discovery Group

Columbus-America Discovery Group was formed in 1985 to conduct multi-disciplinary research; to develop sophisticated deep-ocean technology; and to locate, explore, and recover a deep-ocean shipwreck. The Group was founded by Thomas G. Thompson, a mechanical and ocean engineer with Battelle Memorial Institute in Columbus, OH. He was joined in forming the Group by Robert D. Evans, project director for science and history. The search for SS *Central America* was the first project initiated by the Group. In 1987 Dr. Charles E. Herdendorf of The Ohio State University joined the Group as an oceanographic consultant, and in 1989 he organized the Group's Adjunct Science and Education Program.

The SS *Central America* Project had several goals: 1) to employ scientific methods to locate the shipwreck of the *Central America* and recover gold, oceanographic specimens, and historical artifacts, 2) to employ new technologies for deep-sea exploration and documentation, 3) to add to the historical knowledge of the *Central America* and its era, and 4) to increase the scientific understanding of the deep-ocean environment and its inhabitants. The problems faced by the Group to accomplish these objectives were financial, legal, technical, and operational. The financial challenge was to raise the money needed to fund the search, technology development, and recovery efforts. This was accomplished by forming a limited partnership (Recovery Limited Partnership) with 161 investors providing $12.6 million in capital to underwrite the project (Cook 1989, Ross 1995). The legal problems included protecting the shipwreck from would-be intervening salvors intent on taking advantage of the work done by the Group and mitigating claims of ownership made by insurance companies and others once the gold had been recovered (Horrell 1991, Kellam 1993, Robol 1991, Seanor 1990).

The technical and operational problems faced by the Group are more germane to this paper. The more significant of these included: 1) constructing a probability map estimating the location of the shipwreck and developing a search plan designed to yield a high probability of success in locating it, 2) choosing a wide-swath, high-resolution sonar and developing a convenient, real-time image-processing system using desktop-computer technology and optical storage devices, 3) designing and building a remotely controlled underwater vehicle (submersible) capable of performing the task of recovering gold, delicate archaeological artifacts, scientific specimens, and marine life from depths of up to 3,000 m, 4) obtaining a surface research vessel capable of deploying a submersible and carrying and supporting the necessary other equipment and personnel, 5) hiring and training a crew to perform the sonar search and to maintain and operate the submersible and other recovery and computer equipment, and 6) imbuing the scientists and technicians doing the work with the patience and determination necessary to undertake a multi-year project with an uncertain result (Stone 1992).

Adjunct Science and Education Program

In January 1989 the Adjunct Science and Education Program was organized with the following goals: 1) to foster deep-ocean research at the SS *Central America* shipwreck site in the fields of oceanography, marine biology, marine geology, ocean engineering/technology, and underwater archaeology/maritime history, 2) to establish and coordinate a network of scientists and researchers to take advantage of a unique opportunity to study deep-sea phenomena over a multi-year period, 3) to disseminate research findings to the scientific/technological community, and 4) to produce educational materials based on these findings for all levels of formal education and the general public. The SS *Central America* site presented a unique opportunity to develop techniques for deep-ocean research. The adjunct program was a pioneering effort to develop deep-ocean guidelines and procedures for natural science and archaeological investigations on an historic site. Archives of specimens, artifacts, photographs, and technical data were established for use by the scientific community (see Appendices A and C for locations of specimens and artifacts). The five-year record of the shipwreck investigation consisted of over 3,000 hours of videotape and 25,000 color slides of the ocean floor at the site. This data set has been logged for information relating to the oceanography, marine geology, marine biology, materials science, and underwater archaeology of the site. Several hundred biological and geological specimens have been obtained and preserved, and several thousand artifacts have been recovered and stabilized. A network of over 150 scientists and researchers from seven nations have participated in research projects, examined deep-sea specimens, and analyzed photographs and samples (see Acknowledgements section of this paper).

HISTORY

Scientific investigation of a shipwreck logically begins with uncovering and interpreting surviving documentary evidence of the vessel, its period in history, and the events associated with its sinking—studies that seek not only to understand the course of events but also the reasons, causes, or motives behind them. Muckelroy (1978) considered such work an essential precursor to maritime archaeology but it is equally important to understanding phenomenon of the other physical and biological sciences associated with a shipwreck environment. This event in history has altered the marine environment and influenced the course of physical, chemical, geological, and biological processes at the shipwreck site. In this kind of scientific endeavor history is an important component, thus, it is appropriate that the investigation begins with the events of the mid-nineteenth century.

PANAMA-ROUTE STEAMERS AND THE GOLD RUSH

On 2 February 1848, after two years of war with Mexico, a treaty was signed which ceded California to the

United States. With this expansive acquisition of western territory, President James K. Polk achieved for the nation its "Manifest Destiny"–one country from Atlantic to Pacific. Only nine days before the signing of the treaty, and unbeknownst to either country, James Marshall had discovered gold nuggets in Capt. John Sutter's millrace at Coloma in what was still Mexican California. Marshall had been hired to select a site and build a sawmill to provide lumber for Sutter's enterprises. He found a site on the south fork of the American River, some 80 km northeast of Sutter's Fort at present-day Sacramento, with good stands of pine and plenty of water to drive a mill. Sutter attempted to suppress news of the find until he could secure title to the land on which his partially completed mill stood. But on 15 March 1848, the *Californian*, a San Francisco newspaper, announced to the world:

> GOLD MINE FOUND.—In the newly made raceway of the sawmill recently erected by Captain Sutter, on the American Fork, gold has been found in considerable quantities. One person brought thirty dollars worth to New Helvetia, gathered there in a short time. California, no doubt, is rich in mineral wealth; great chances here for scientific capitalists. Gold has been found in almost every part of the country.

By year's end 10,000 gold seekers flooded into the upper Sacramento watershed. Gold nuggets and dust approaching $250,000 in value were taken from California stream beds in 1848 (~$4.6 million in 1995 gold value). Most of it found its way to San Francisco, where much of it was shipped abroad, spreading news of the discovery. The east coast was slow to respond; scattered newspaper accounts of California gold did not attract widespread attention until an official report was received from the territorial governor (Paul 1947).

In the early summer of 1848, Colonel Richard B. Mason, military governor of California, and Lt. William Tecumseh Sherman, toured the gold fields. They estimated 4,000 men were working the gold district, daily extracting $30,000 or more in gold. Col. Mason obtained samples worth $3,900 (according to a subsequent assay by the U.S. Mint in Philadelphia) and sent these with his report to Washington. The report was the highlight of President Polk's opening message to the second session of the 30th Congress, 5 December 1848. In his address Polk said that at the time of California's acquisition it was known that precious metals existed there but, "The accounts of the abundance of gold in that territory are of such an extraordinary character as would scarcely command belief were they not corroborated by authentic reports." (Johnson 1974). The presence of California gold in the national capital and the President's statement made headline news throughout America and around the world. Gold fever became an epidemic as "argonauts" (name adopted by California gold seekers in 1849; also known as forty-niners) swarmed West by the thousands. In California, a miner could take a fortune from the hills and streams with little more than a shovel and a tin pan (Fig. 2).

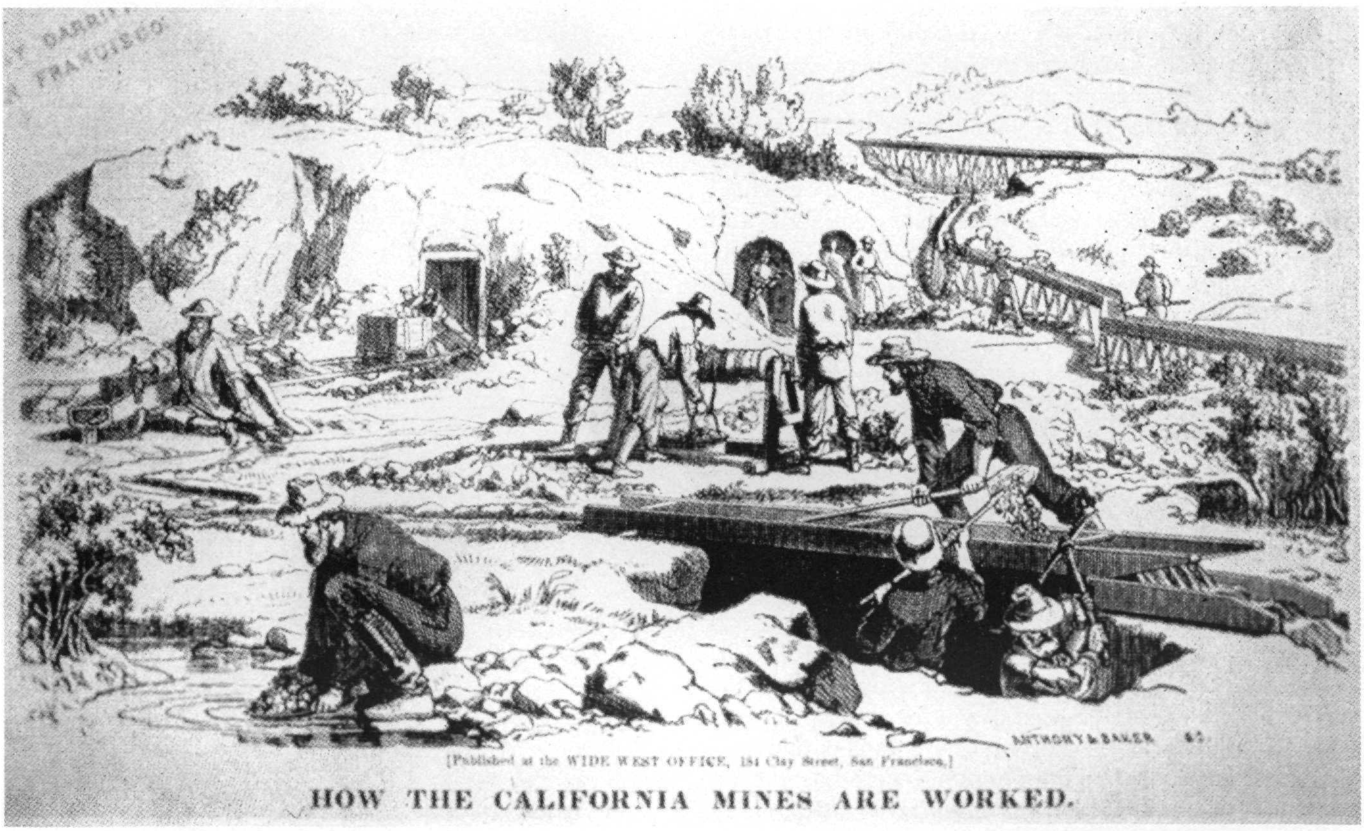

FIGURE 2. Mining techniques used in the California gold fields. Woodcut from a contemporary letter-sheet, published by the Wide West Office, San Francisco (circa 1852) and distributed by the *Noisy Carriers*. Letter-sheets were sold to miners so that they could write home an illustrated account of their life in the mines. From left to right, the woodcut shows miners: washing with a cradle or rocker, washing with a pan, tunnel mining, mining through a shaft, washing with a long tom, and washing with a line of sluices from a water company's aqueduct. Reproduced from Paul (1947).

Thus began the saga of the forty-niners; strike it rich or not (and most did not), the adventure alone was often treasure enough for a lifetime.

The discovery of gold on the Pacific coast led to the rapid settlement of California by people from every state and territory in the Union as well as immigrants of almost every nationality on the globe. The estimated 1848 population of California, exclusive of the Indian Nations, was 14,000. This number swelled to about 102,000 in 1850; 223,000 in 1852; 380,000 in 1860; and by 1870 reached 625,000 (Paul 1947). Sadly, the native population declined from about 150,000 to 30,000 during the same period (Sachs 1986). Yet for nine years following the discovery of gold, and despite the large numbers of new inhabitants, regularly scheduled mail by Panama steamer was received in San Francisco only twice a month. Various overland routes were pioneered in the 1850s, and by June 1859 there were no less than six different routes for conveying the mails to and from California, including both steamers and overland stages. The aggregated cost to the Government for operating these routes was enormous—$2,185,000—while the total receipts amounted to only $340,000. The highest cost on any route was the semi-monthly service by ocean steamer from New York to San Francisco at $738,000, from which the annual receipts were $230,000 (Root and Connelley 1901).

During the Gold Rush there were three principal routes to California: 1) the four- to eight-month trek overland from Missouri, 2) the three- to eight-month sailing ship voyage that included the hazardous passage around Cape Horn, and 3) the three- to four-week side-wheel steamer trip via Panama. For two decades (1848 to 1869) the Panama Route was the preferred but most expensive passenger transportation link between the Atlantic and Pacific coasts of the United States. Annually, thousands traveled westward and eastward over it, as did enormous amounts of mail and tons of gold cargo. Side-wheel steamships were generally used for the Atlantic and Pacific legs of the route (Fig. 3), while during the early years river rafts, dugout canoes, and mule trains were employed for the arduous journey across the Isthmus. In 1855 the Panama Railroad (Fig. 4) opened service between Panama City on the Pacific and Aspinwall (present-day Colon, Panama) on the Atlantic, which cut the difficult two-week crossing to only four hours. The Panama Route thus formed a vital communication system for the rapidly expanding United States. The more rigorous overland route and the more treacherous voyage around Cape Horn could not compare with the Panama Route for speed or dependability (Kemble 1943).

California gold production rose from less than $250,000 in 1848 to over $80 million in 1852 (Fig. 5). Gold was California's most important commodity for export during this period, and nearly all the gold of California was shipped on steamers until the completion of the trans-continental railroad in 1869. Fees for carrying gold were based on a proportion of its value, ranging from 2.5% in 1850 to only 0.25% in 1860 (Kemble 1943). An estimated $757,068,800 in gold specie (metal money) was shipped from San Francisco by way of the Isthmus (Panama and Nicaragua) during the period 1848 to 1869 (Panama alone accounted for over $710 million), with the highest value in 1853 when $54,947,800 was sent (Fig. 6). During the same period 479,774 passengers traveled from New York to San

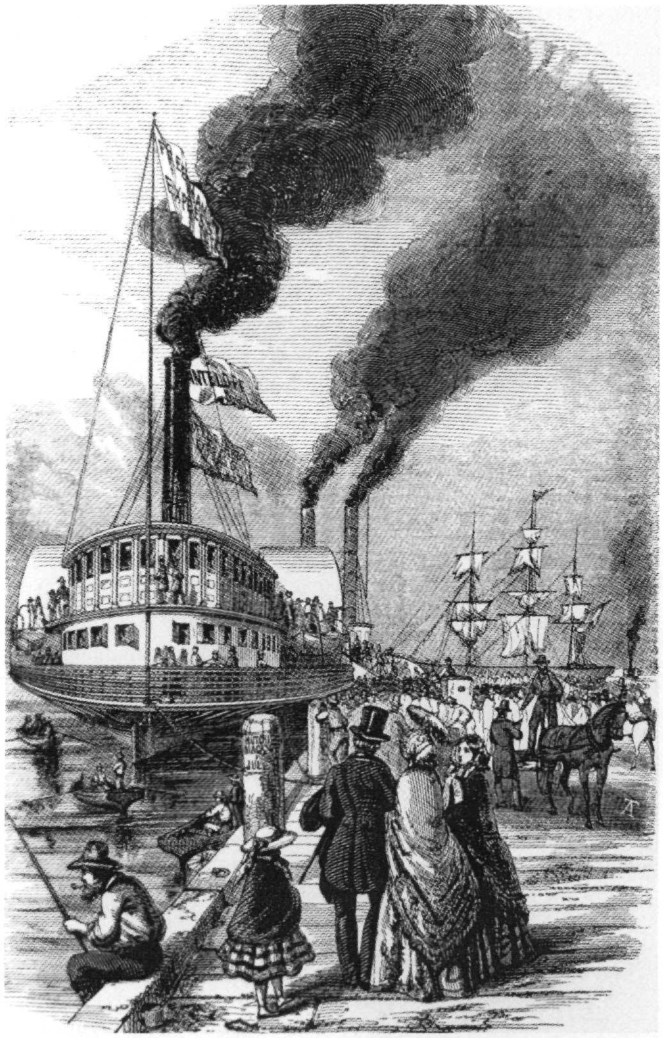

FIGURE 3. Steamers *Antelope* and *Bragdon* at the Jackson Street wharf in San Francisco, circa 1859. Reproduced from *Hutchings California Magazine*, July 1859.

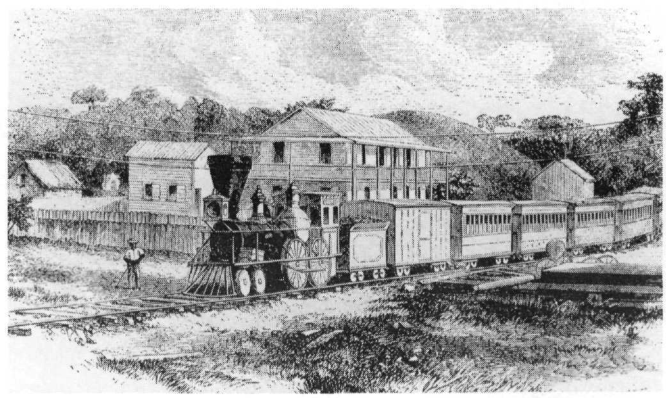

FIGURE 4. Panama Railroad train passing through San Pablo, New Granada. Completed in 1855, this railroad spanned the Isthmus of Panama and connected the Atlantic and Pacific legs of the steamship route between New York City and San Francisco. Reproduced from Kemble (1943).

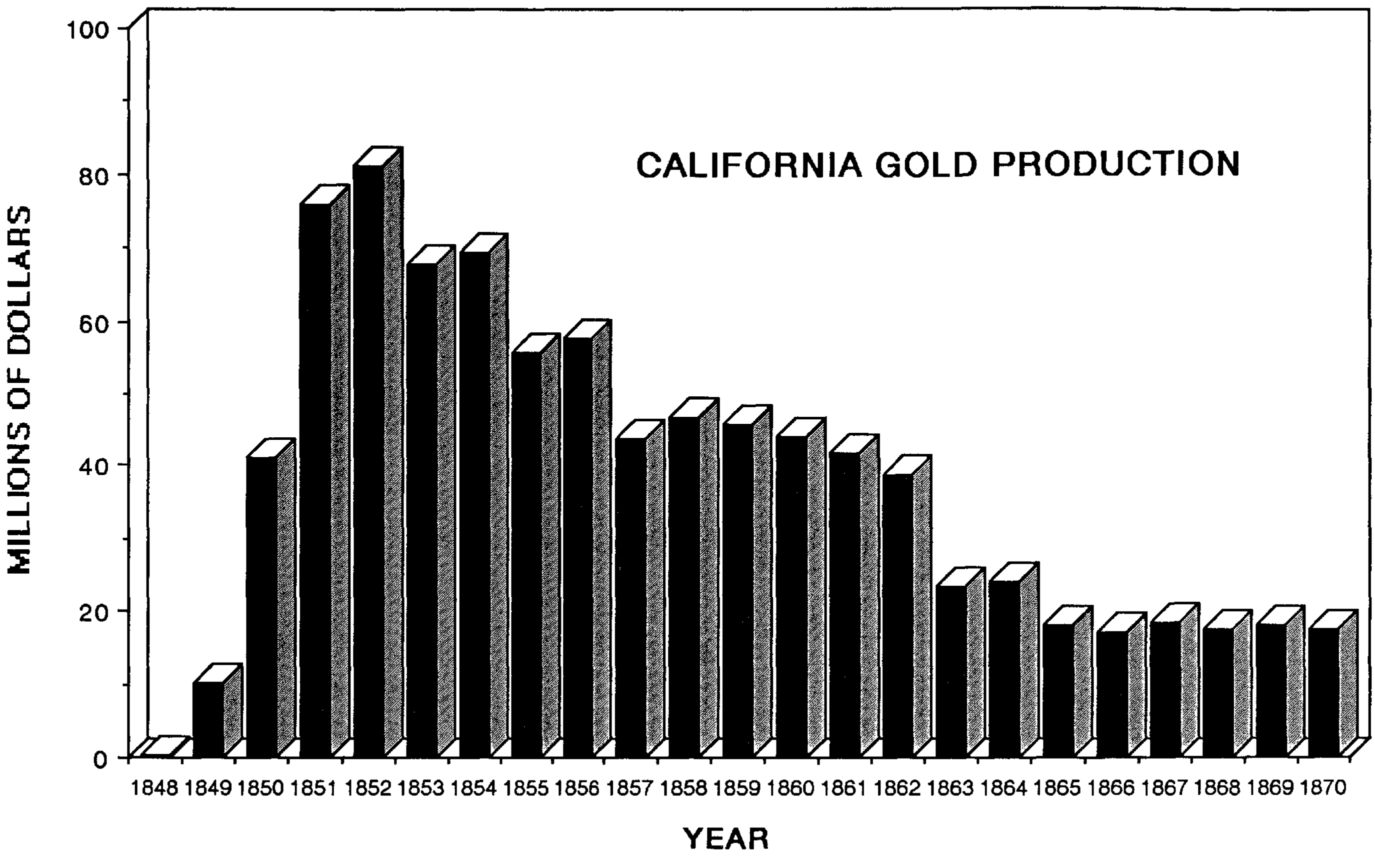

FIGURE 5. California gold production during the Gold Rush, 1848 to 1870. Data sources: Day (1897), Hill (1929), and Paul (1947).

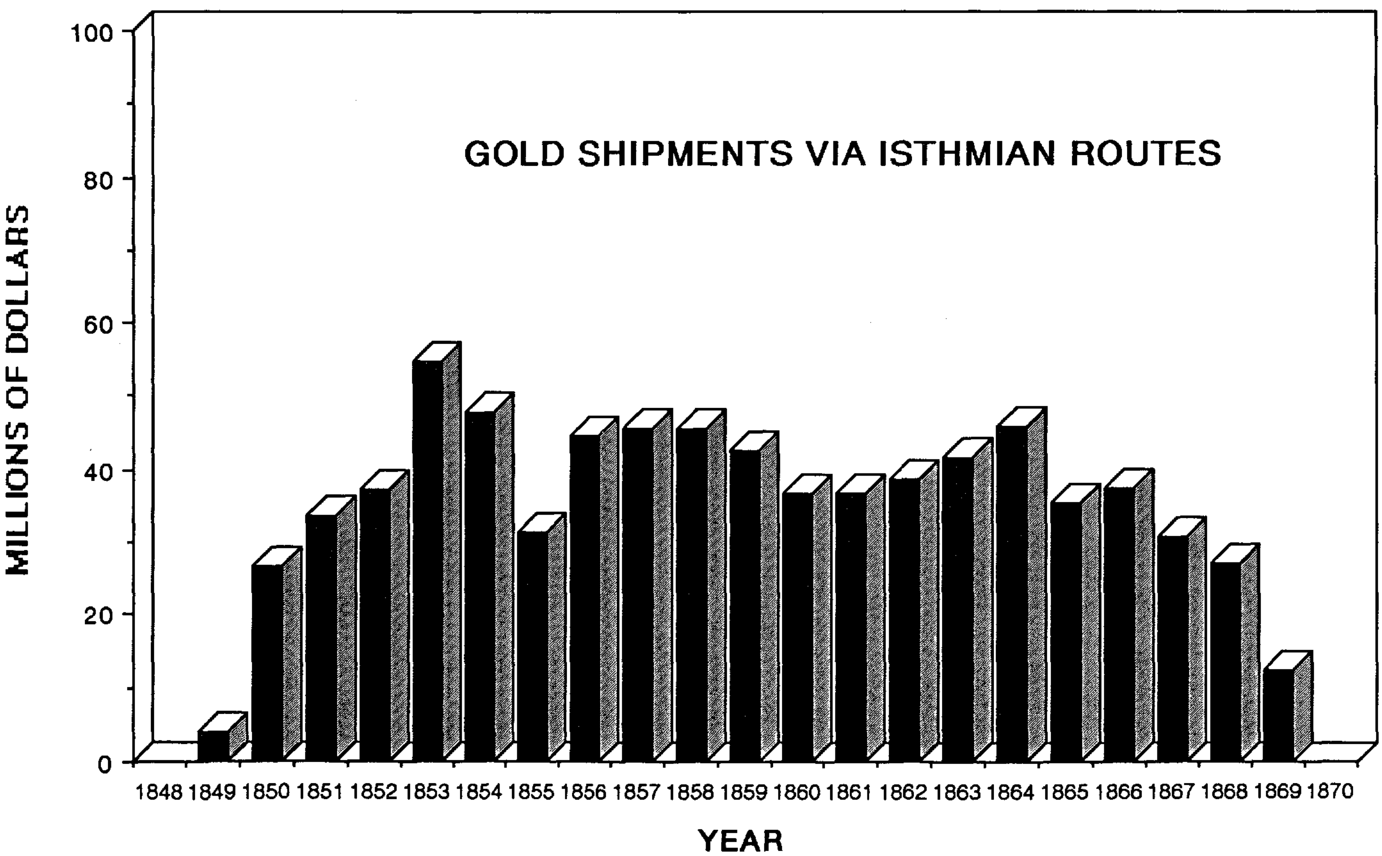

FIGURE 6. Gold shipments from San Francisco via the Isthmian Routes, 1848 to 1870. Data source: Kemble (1943).

Francisco via the Isthmus, while 295,698 returned by the same route (Figs. 7, 8). The SS *Central America* transported approximately 7.2% of the gold and 6.2% of the passengers carried by Panama Route steamers (Table 1).

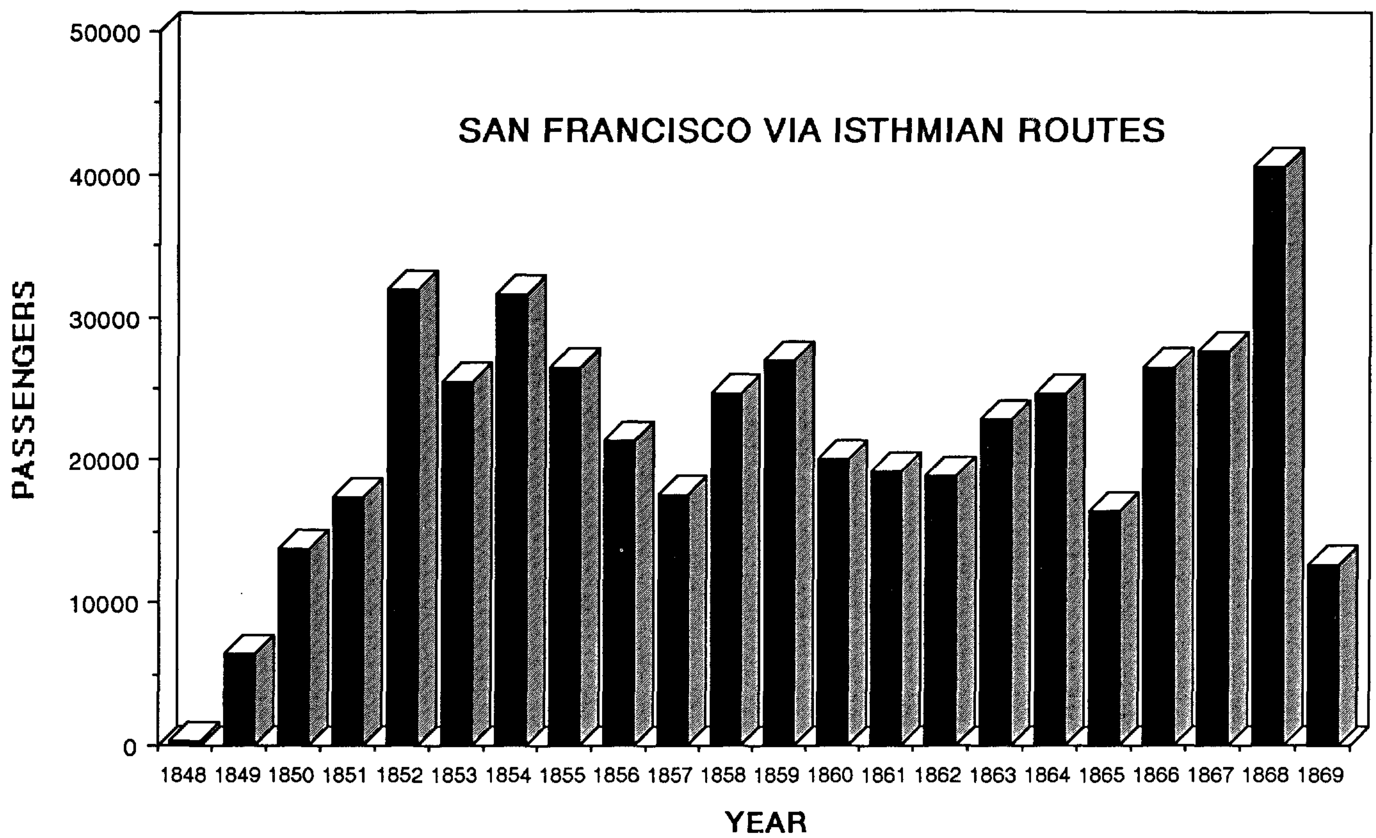

FIGURE 7. West-bound (San Francisco) steamer passengers via the Isthmian Routes 1848 to 1869. Data source: Kemble (1943).

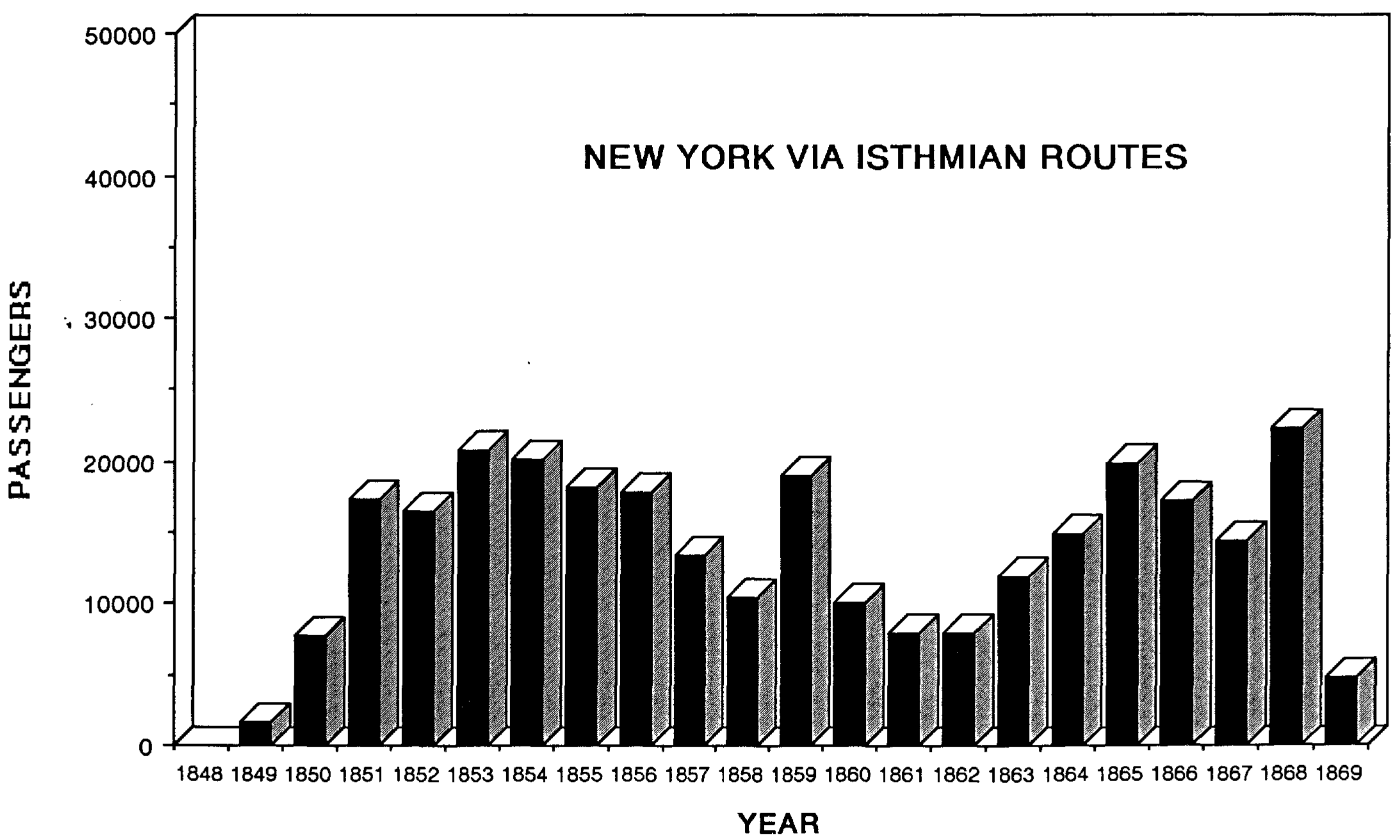

FIGURE 8. East-bound (New York) passengers via the Isthmian Routes 1848 to 1869. Data source: Kemble (1943).

TABLE 1

Voyages of the SS Central America.

Voyage	Captain	Outbound New York–Aspinwall Date	Outbound Passengers	Inbound Aspinwall-New York Date	Inbound Passengers	Gold Shipment
1	McGowan	10/20/1853	800	11/10/1853	465	$872,831
2	McGowan	11/21		12/12	467	887,666
3	McGowan	12/20		1/9/1854	239	537,609
4	McGowan	1/20/1854		2/11	308	809,141
5	McGowan	2/20		3/14	241	978,383
6	McGowan	3/20		4/8	508	803,569
7	Fox	4/20		5/8	584	847,573
8	Fox	5/20		6/8	434	973,472
9	Fox	6/20		7/9	448	1,150,332
		Routine ship repairs (July 1854 – 3 weeks)				
10	Fox	8/5		8/24	288	1,212,582
11	Fox	9/5		9/26	737	1,202,272
12	Fox	10/5		10/27	508	1,082,684
13	Fox	11/6		11/24	423	1,568,644
14	Fox	12/5		12/25	224	1,461,646
15	McKinstry	1/5/1855		1/25/1855	206	1,251,565
16	McKinstry	2/5	473	2/25	304	1,113,547
17	Fox	3/5		3/24	234	317,800
18	Fox	4/5		4/24	372	772,011
19	Fox	5/5		5/24	817	1,324,025
20	Gray	6/5		6/25	714	1,052,287
21	Gray	7/5		7/25	394	850,213
22	Gray	8/6		8/25	442	1,285,616
23	Gray	9/5		10/2	396	755,172
24	Gray	10/5		10/30	550	1,670,477
25	Herndon	11/5		11/30	575	1,939,592
26	Herndon	12/7		12/28	275	1,405,392
27	Herndon	1/5/1856		1/30/1856	338	881,000
		Routine ship repairs (February 1856 – 3 weeks)				
28	Herndon	2/20		3/15	310	1,219,053
29	Herndon	3/20		4/16		1,458,502
30	Herndon	4/21		5/16		1,687,916
31	Herndon	5/20		6/13		1,951,721
32	Herndon	6/20		7/14	350	1,705,301
		Routine ship repairs (July/August 1856 – 5 weeks)				
33	Herndon	8/23		9/14		1,607,658
34	Herndon	9/20		10/12		1,686,233
35	Herndon	10/20		11/13		1,626,507
36	Herndon	11/20		12/13		1,599,600
37	Herndon	12/20		1/13/1857		1,269,177
38	Herndon	1/21/1857		2/13		1,097,806
39	Hunter	2/20		3/16		1,004,956
40	Herndon	3/20		4/13		1,229,238
41	Herndon	4/20		5/13		1,707,527
42	Herndon	5/20		6/12		1,920,376
		Routine ship repairs (June/July 1857 – 5 weeks)				
43	Herndon	7/20	275	8/12		1,245,805
44	Herndon	8/20		Sank 9/12	476	1,219,189
						$54,243,666

Data Sources: *New-York Times* (1853 to 1857), Kemble (1943), and Ridgely-Nevitt (1944).

As California concerned itself with producing gold, little effort was expended on the local production of consumer goods or even mining equipment. Thus, nearly everything had to be imported from markets in New York, Boston, London, and a variety of lesser ports. Food stuffs and building supplies—notably brick, ironwork, glass, and lumber—were particularly lucrative cargoes, as well as prefabricated wood and iron buildings (Delgado 1990). Cargoes arrived almost daily in clipper ships by way of Cape Horn while gold was exported biweekly on steamers to pay for these goods. The effect of the inflow of California gold upon the development of the United States, particularly in generating new commerce and industry, was great and unprecedented. Kemble (1943) also points out that it was an important factor in supporting the credit of the Union during the Civil War.

The shipbuilders of New York produced most of the Panama Route steamers—87 of the 108 steamships which served on the Isthmian Routes (Kemble 1943). Along the East River side of lower Manhattan Island stretched the shipyards of the major builders: William H. Webb, Jacob A. Westervelt, William H. Brown, and Jeremiah Simonson. At Webb's yard, on 25 March 1852, the keel was laid for the *George Law* (renamed *Central America* in 1857). William H. Webb was one of the foremost shipbuilders of the nineteenth century, an era that saw the development of the clipper ship, the steam-propelled vessel, and the iron-clad warship (Dunbaugh and Thomas 1989). From 1840 to 1869 his shipyard produced 135 vessels, ranging from small fishing craft to packets or clippers that crossed the oceans to larger steam-powered liners, including 17 side-wheel steamers for the Panama Route which serviced the California Gold Rush trade (Table 2)—more than any other builder. As head of the shipyard, in which he was both naval architect and shipwright, he was known for his attention to detail (Dunbaugh and Thomas 1989).

During the construction of the *Central America* the William Webb yards had no less than 10 other vessels under construction, including three schooners, a bark, a brig, a clipper, a packet, a ship, and two other steamships. The *Central America* was an intermediate design between Webb's early and late steamships. His early steamships (circa 1848) were two-decked vessels about 65 m long with high bulwarks, clipper bows, and side-lever engines (i.e., *Tennessee*). The Webb yard's intermediate-class steamers were about 85 m long, had finer lines, a ratio of length to breadth of 6:5:1, and three decks to accommodate more passengers. In this class the bulwarks gave way to open rails, sail plans diminished, bowsprits became short spikes, and oscillating or inclined engines replaced the side-lever type. An innovation that was started with the *Tennessee,* and further developed in the *Central America,* to obtain as much room as possible for engines and coal was a flat bottom with no deadrise (vertical distance from the top of the keel to the curved portion of the hull) (Ridgely-Nevitt 1944). Webb's late steamships (circa 1863) differed widely from the *Central America* by virtue of increased length (about

TABLE 2

Steamships built by William H. Webb for Panama Route service.

Steamer	Engine Builder	Year Built	Engine Type/No	Engine HP/psi	Cylinder Dia (in)	Piston Stroke	Paddle Wheel	Hull Dimensions	Tonnage	Panama Route Line
California	Novelty	1848	s-l /1	-	70	8	26	200x34x20	1,057	PMS
Cherokee	Novelty	1848	s-l /1	500/16	75	8	31	211x35x15	1,244	NYSSN
Goliah	Morgan	1848	v-b /1	250	50	8	-	185x29x13	613	WL
Panama	Allaire	1848	s-l /1	550	70	8	26	200x34x20	1,139	PMS
Tennessee	Novelty	1848	s-l /1	500/16	75	8	32	212x36x22	1,275	NYSSN
Golden Gate	Novelty	1850	osc /2	1,150/12	85	9	31	262x40x31	2,067	PMS
Union	Allaire	1850	s-l /2	830/17	60	7	30	215x34x22	1,200	ST
*George Law**	Morgan	1852	inc /2	1,000/20	65	10	32	272x40x32	2,141	USMS
James Adger	Allaire	1852	s-l /1	-	75	8	-	215x32x21	1,151	ST
San Francisco	Morgan	1853	osc /2	1,000/20	65	8	28	276x40x24	2,272	PMS
Moses Taylor	Cun Bel	1857	v-b /2	-	50	10	-	246x34x17	1,370	USMS
Constitution	Novelty	1860	w-b /1	-	105	12	40	340x45x32	3,315	PMS
Golden City	Novelty	1862	v-b /1	1,800	105	12	40	343x45x30	3,373	PMS
Colorado	Novelty	1863	v-b /2	-	105	12	-	340x45x32	3,357	PMS
Sacramento	Novelty	1863	v-b /1	-	103	12	-	304x43x29	2,647	PMS
Henry Chauncey	Novelty	1864	v-b /1	-	105	12	-	319x43x28	2,656	PMS
China	Novelty	1866	v-b /1	1,500	105	12	40	360x48x32	3,836	PMS

Engine Builder:
Allaire - Allaire Iron Works
Cun Bel - Cunningham, Belknap & Company
Morgan - Morgan Iron Works (incl. T. F. Secor & Co.)
Novelty - Novelty Iron Works

Engine Types:
inc - inclined
osc - oscillating
s-l - side lever
v-b - vertical beam
w-b - walking beam

Paddle Wheel:
diameter (ft)

Panama Route Steamship Lines:
NYSSN - New York & Savannah Steam Navigation Company
PMS - Pacific Mail Steamship Company
ST - Spofford, Tileston & Company
USMS - United States Mail Steamship Company
WL - J. T. Wright Line

Piston Stroke:
length (ft)

Hull Dimensions:
length x beam x depth of hold (ft)

**George Law* renamed *Central America* in 1857.
Data Sources: Dunbaugh and Thomas (1989), Kemble (1943), and Ridgely-Nevitt (1981).

100 m), added superstructures to quarter more passengers, a length-beam ratio of 7:1, and vertical-beam engines (i.e., *Golden City* and *China*).

The several "ironworks" which constructed engines for the steamers were located on the East River near the shipyards. Morgan Iron Works, Novelty Iron Works, and Allaire Iron Works were the principal builders of steam engines for Panama steamers. After being launched on 28 October 1852, the *Central America* was towed to nearby Morgan Iron Works where her two inclined engines were installed. The Morgan Iron Works began in 1838 when Charles Morgan, T. F. Secor, and William H. Caulkins leased eight lots at the foot of 9th Street on the East River, New York City, and organized for the purpose of building steamship engines (trading as T. F. Secor & Company during the early years). The first engines were built for the steamer *Savannah* and the steamboat *Troy* of the Troy Line. Although largely destroyed by fire in 1841, the works had been rebuilt and grown by 1846 to encompass the entire block bounded by 9th Street, 10th Street, Avenue D, and the East River, as well as a half block on the south side of 9th street for offices and drafting rooms. Morgan went on to become a leader in coastwise shipping and railroading, and in 1850, George W. Quintard became sole proprietor of the works. Under his direction, steam hammers, floating derricks, new docks, and heavy machine-shop equipment were installed. Some of the largest river- and ocean-going merchant and war vessels were engined by Quintard. During the period 1847 to 1864, Morgan Iron Works provided engines for 23 steamships that operated on the Panama Route, including the *Central America* (Table 3).

TABLE 3

Steamship engines built by Morgan Iron Works for Panama Route steamers.

Steamer	Ship-builder	Year Built	Engine Type/No	Engine HP/psi	Cylinder Dia (in)	Piston Stroke	Paddle Wheel	Hull Dimensions	Tonnage	Panama Route Line
Antelope	B & S	1847	- /1	-	-	-	-	179x28x17	650	PMS
Crescent City	Brown	1848	s-l/1	600	80	9	34	234x34x23	1,291	USMS
Georgia	S & D	1848	s-l/2	681	90	8	36	248x49x33	2,727	USMS
Goliah	Webb	1848	v-b/1	250	50	8	-	185x29x13	613	WL
New Orleans	(in NY)	1848	v-b/1	131	52	11	32	209x30x12	762	ECL
Ohio	B & S	1848	s-l/2	681/15	90	8	36	246x46x33	2,432	USMS
Empire City	Brown	1849	s-l/1	-	75	9	-	239x39x24	1,751	ECL, USMS
Brother Jonathan	PPS	1850	- /2	-	72	11	33	220x36x14	1,360	VL
North America	L & S	1850	- /1	-	60	12	-	261x34x21	1,440	VL
Winfield Scott	W & M	1850	s-l/2	370	66	8	-	225x35x29	1,292	NYSF, PMS
United States	Collyer	1851	v-b/1	-	60	12	-	230x33x20	1,216	USMS
Sierra Nevada	Collyer	1851	v-b/2	-	42	10	-	223x34x17	1,257	ECL, VL
*George Law**	Webb	1852	inc/2	1,000/20	65	10	32	272x40x32	2,141	USMS
Cortes	W & M	1852	wb/2	-	42	10	-	221x23x17	1,117	NYC, APS
Golden Age	Brown	1853	v-b/1	- /27	83	12	-	273x42x25	2,182	PMS
San Francisco	Webb	1853	osc/2	1,000/20	65	8	28	276x40x24	2,272	PMS
Sonora	W & C	1853	v-b/2	675/20	50	10	30	269x36x24	1,617	PMS
Orizaba	W & C	1854	v-b/1	-	65	11	32	246x35x18	1,451	VL, PMS
St. Louis	W & C	1854	v-b/2	675/22	50	10	30	266x36x16	1,621	PMS
Fulton	S & D	1855	osc/2	-	65	10	-	288x41x32	2,308	NAS
Ocean Queen	W & C	1857	v-b/1	-	90	12	38	327x42x23	2,802	VL
Golden Rule	Steers	1863	v-b/1	-	81	12	30	304x44x24	2,768	CAT
Guiding Star	RJW	1864	v-b/1	-	81	12	-	301x41x33	2,384	NAS

Shipbuilder:
B & S - Bishop & Simonson (New York)
Brown - William H. Brown (New York)
Collyer - Thomas Collyer, William Collyer (New York)
L & S - Lawrence & Sneeden (New York)
PPS - Perine, Patterson & Stack (Williamsburg, NY)
RJW - Roosevelt, Joyce & Waterbury (New York)
S & D - Smith & Dimon (New York)
Steers - Henry Steers (Greenport, NY)
W & C Westervelt & Co. (New York)
W & M - Westervelt & Mackey (New York)
Webb - William H. Webb (New York)

Panama Route Steamship Lines:
APS - Atlantic & Pacific Steamship Company
CAT - Central American Transit Company
ECL - Empire City Line
NAS - North American Steamship Company
NYC - New York & California Steamship Company
NYSF - New York & San Francisco Steamship Line
PMS - Pacific Mail Steamship Company
USMS - United States Mail Steamship Company
VL - Vanderbilt Line
WL - J. T. Wright Line

Hull Dimensions:
length x beam x depth of hold (ft)

Engine types:
inc - inclined
osc - oscillating
s-l - side lever
v-b - vertical beam
wb - walking beam

Piston Stroke:
length (ft)

Paddle Wheel:
diameter (ft)

**George Law* renamed *Central America* in 1857.
Note: Includes engines built by T. F. Secor & Co. before name changed to Morgan Iron Works.
Data Sources: Dunbaugh and Thomas (1989), Kemble (1943), and Ridgely-Nevitt (1981).

SS *CENTRAL AMERICA*

Characteristics

The SS *Central America* was a wooden-hulled, three-masted side-wheel steamship (Fig. 9). The ship was 83 m long, 12 m wide, and had a 10 m depth of hold. The decks were constructed of pine. Oak was used for the hanging knees that connected the decks to the hull. The outer surface of the hull was sheathed with copper plates to protect it from shipworm invasion. She had three principal decks: 1) spar or weather deck, 2) main or second deck, and 3) lower or third deck (Fig. 10). A hurricane deck was located on top of the pilothouse and other deckhouses. For storage of cargo, bow and stern orlop decks were built into the hold below the lower deck. Cabin class passengers (First and Second Cabin) occupied staterooms in the aft portions of the second and third decks. The *Central America* had space for 110 cabin class passengers based on single berths two high. Up to 384 steerage class passengers were located forward on the second and third decks based on double bunks, stacked three-high, against the side of the ship. The crew was berthed in the bow on the second deck and the officers' cabins were located on the spar deck. However, the number of berths did not limit the number of people carried to and from the gold fields. For example, in May 1855 she arrived in New York with 817 passengers (Ridgely-Nevitt 1944).

Inspection of what is believed to be a contemporary model of the SS *Central America* at the U.S. Naval Academy Museum in Annapolis, MD, suggests that the ship was barkentine-rigged. A barkentine of the mid-nineteenth century was a three-masted sailing ship having only the foremast square-rigged and the mainmast and mizzenmast fore-and-aft rigged. No sail plan for the vessel has been located but the model clearly shows gaff spars projecting aft from each of the masts. Spars of this type were used in conjunction with fore-and-aft sails (spencers). The presence of two horizontal yards on the foremast indicates that this mast also carried two square-rigged sails (foresails).

Half a century ago Prof. Cedric Ridgely-Nevitt, Webb Institute of Naval Architecture, conducted a thorough assessment of the design, construction, and operation of the *Central America* ex-*George Law*. His exhaustive research forms the basis for much of what is known about the details of the ship in the absence of original deck drawings and a profile of the ship. The following description of the vessel components relies heavily on the work of Ridgely-Nevitt (1944) and the ship model at the Naval Academy.

The *Central America's* spar deck was a spacious expanse of planking broken only by a series of hatches. In weather these gave light and ventilation to the accommodations below (it is unclear if these deck openings were glass-covered skylights or simply wooden gratings). Bounding the deck was an open rail to which was lashed a rope netting. Against its stanchions were erected wooden benches. Aft of the foremast was the pilothouse which was fitted with a large, double steering-wheel.

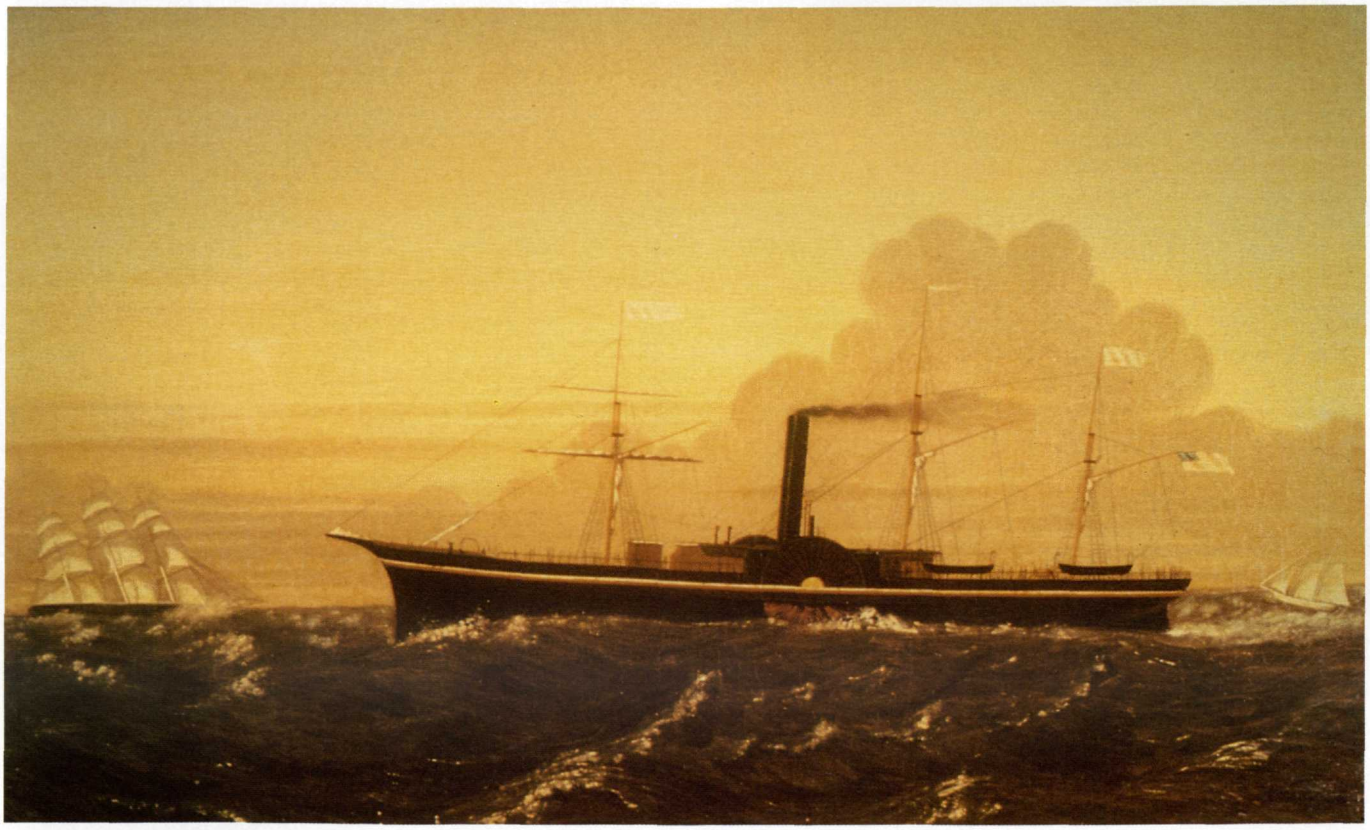

FIGURE 9. Steamship *George Law* (renamed *Central America* in 1857), painter unknown (American 1852). Reproduction courtesy of The Mariners' Museum, Newport News, VA.

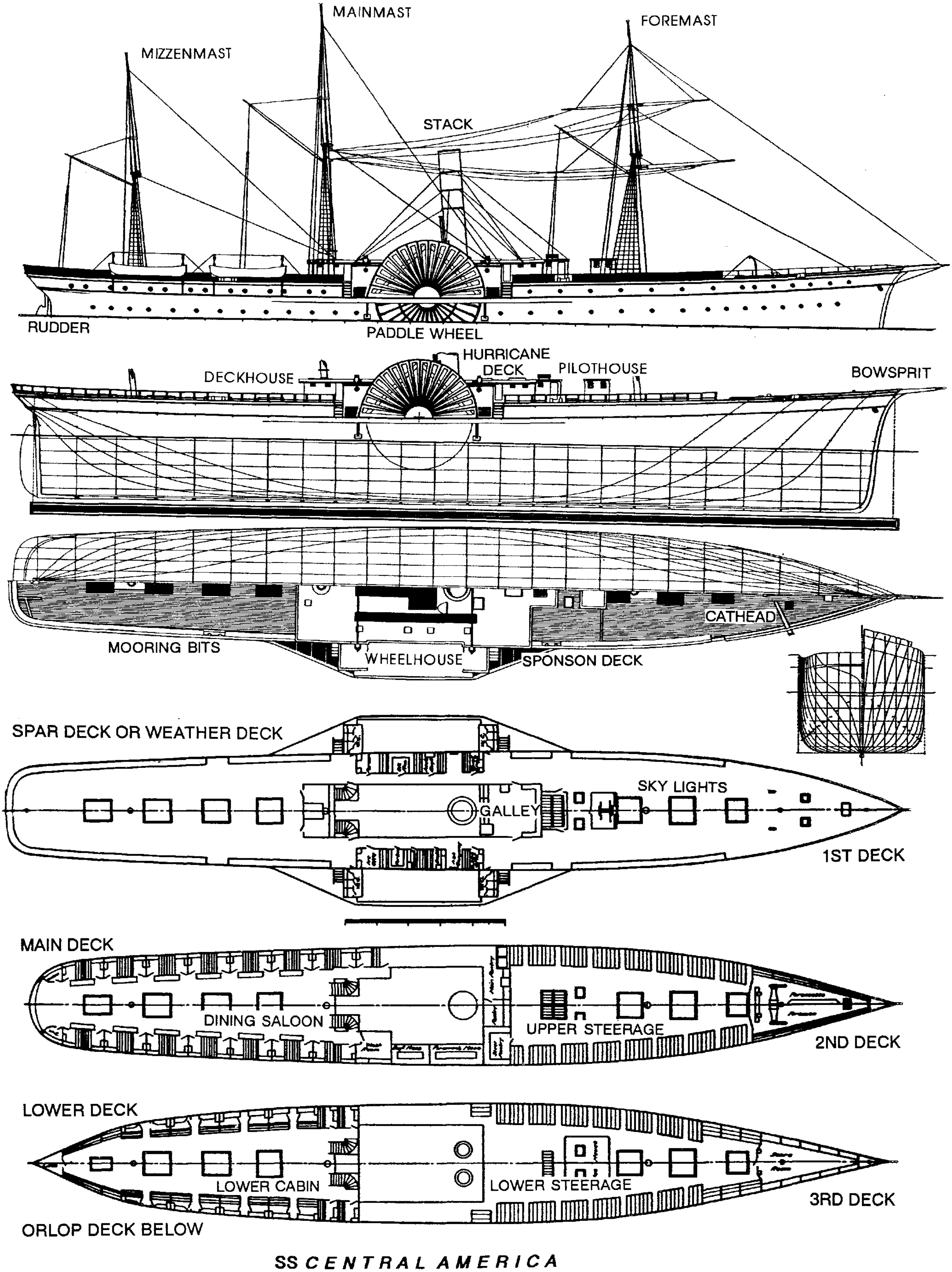

FIGURE 10. Rigging, hull, and deck plans for the SS *Central America* modified from Ridgely-Nevitt (1944). The lateral cross-section, at right center, is a split view showing the bow end of the ship on the right, and the stern end on the left. The major divisions on the bar scale, shown between the 1st and 2nd decks, are equivalent to 10 ft (~3 m).

Continuing toward the stern were two small hatches giving access to an insulated compartment on the third deck for perishable provisions and ice. Next came a companionway leading to the forward steerage area. The galley was located just forward of the smokestack (the *Central America* only had one stack, not two as shown in some illustrations drawn after the sinking). The central deckhouse enclosed part of the machinery space with a pair of curving stairways leading to the Captain's stateroom near the mainmast and the lower decks. The cabins of the other officers as well as the doctor, purser, and baggage master were set mid-ship next to the paddle boxes. Three water closets were located fore and aft of both the port and starboard paddle-box guards on the sponson deck. Ash gangways on the inboard side of each paddle box were used to dump boiler ashes overboard through a scuttle.

On the second deck, the crew was berthed in the bow, with a center-line bulkhead separating the "black gang" (boiler-room crew) from the deck force. At the after end of the forecastle were the windlass and bits for the anchor chain. This arrangement for handling the anchor gave the passengers the use of an unobstructed upper deck (with the possible exception of capstans fore and aft) but it made for uncomfortable conditions for the crew. Steerage passengers were carried in the forward portion of the second and third decks behind the forecastle. The placement of berths against the side of the ship left the center clear for serving meals. Underneath the galley, and connected to it by a dumb waiter, was a three-compartment pantry that served both the steerage forward and the dining saloon aft. The cabin passengers occupied staterooms on the after portions of the second and third decks. The staterooms were compact and constructed along the sides of the ship thus leaving the center areas unoccupied. A dining saloon for all cabin passengers was located in this area on the main deck. The large hatches on the spar deck were repeated on the deck below for the triple purpose of admitting light, air, and cargo.

Using the model at the Naval Academy as a guide, the hull was black above the waterline with the lower wales (rubbing stakes that ran the full length of both sides of the ship) painted red. The forward fancy rail was varnished, as well as all the deckhouses, with the exception of a narrow white band in the molding around their top. The deckhouse tops were covered with canvas and painted gray. The paddle wheels were red and the black funnel had a red band at its top. The paddle boxes were black except for a gold semicircle at their centers. The lifeboats were also painted black. The masts, bowsprit, and the upper deck were natural, unpainted wood. An unsigned 1852 painting of the *George Law* in the Mariner's Museum, Newport News, VA, is consistent with the above description (Fig. 9).

The ship was powered by two huge inclined steam engines which drove mid-ship paddle wheels. The diameter of these bright red side-wheels was about 10 m. The *Central America* had a maximum speed of 13 knots and a cruising speed of 11 knots. The engine machinery and the massive boilers added 750 tons of ironworks to the total weight. The ship's displacement was listed as 3,000 tons on published plans (Webb 1895) and 2,141 tons on registration documents (National Archives).

The steam-generating boilers on the *Central America* were large, iron receptacles into which water was pumped. They were most likely "fire tube boilers," which were designed to pass hot furnace gases through tubes in the water receptacle. The advantage of this type of boiler was its simple operation but the steam-generating efficiency was relatively low because of the limited grate area and the slow circulation of water. Also, this type of boiler operated at low pressures (15 to 20 lbs/in^2 or 103 to 138 kPa), thereby reducing the likelihood of explosion but its relatively large size took up considerable space. Large amounts of coal were needed to fire these boilers, approximately 1,200 tons to make the 20-day round trip journey from New York to Panama. The ship had only one funnel (smokestack) which was connected by a "Y" tube to the two boilers.

The twin engines of the *Central America* utilized steam, produced under pressure in the coal-fired boilers, to drive the massive side wheels. The steam from each boiler entered a valved steamchest and was then admitted into a cylinder in which there was a piston. The energy released by the expanding steam forced the piston to move. When the piston had traveled to the end of the cylinder and thus completed its 3-m stroke, the expended steam was allowed to escape from the cylinder. At the same time, a slide valve allowed live steam to be admitted to the other side of the piston, which caused it to travel back to the other end of the stroke. A steam engine of this type was called "double-acting" because the force of the steam was applied alternately on the two sides of the piston (Van Amerongen 1967). While the piston was forced in one direction by the expanding steam, the spent steam was pushed out an exhaust port in the cylinder on the other side of the piston. Reversing the steam flow from one side of the piston to the other was effected automatically by a control device called a slide valve, which alternately covered the steam inlet and exhaust ports. The slide valve was linked to a drive mechanism so that its to-and-fro motions were at the same rate as the piston. The spent steam that emerged from the cylinder was passed to a condenser (most likely through tubes surrounded by cold water) where it was cooled and precipitated as water. The water was then reheated in the boiler and the cycle was repeated. Periodically, as salt built up in the boilers, they would have to be "blowndown" or flushed to remove the extremely corrosive salt solution (Ridgely-Nevitt 1981).

The transmission of the to-and-fro motion of the piston to the rotary motion of the crankshaft and side wheels was effected through a crosshead (reciprocating blocks which slid between two guiding slots) which formed the junction piece between the piston rod and a connecting rod. One end of the connecting rod was pivotally attached to the crosshead and the other end was connected to a crank arm at the end of the crank shaft. The crosshead transmitted to-and-fro movement to the crank arm, which produced the rotary movement of the shaft, which drove the side wheel (Fig. 11). The speed of the engines was controlled by a fly-ball governor.

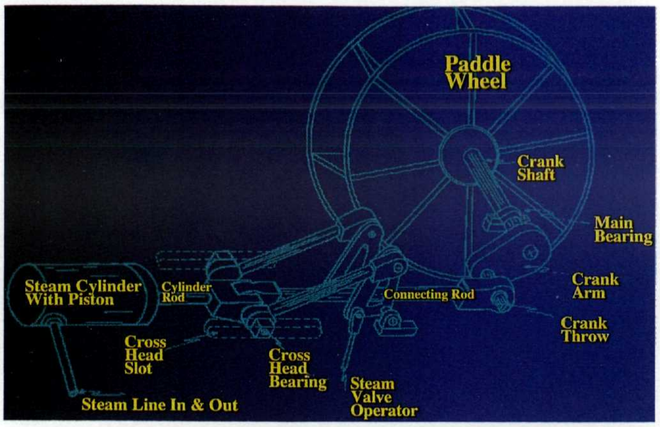

FIGURE 11. Generalized drawing of the engineworks on board the SS *Central America*. The Morgan Iron Works-built machinery weighed 750 tons and included two inclined steam engines each with a 165-cm diameter cylinder and a 3-m stroke. Port and starboard paddle wheels, each 10 m in diameter, drove the vessel at a cruising speed of 11 knots. Drawing courtesy of Donald J. Hackman.

The ships on the Panama Route burned coal. The amount burned by the *Central America* is not known with certainty but it can be estimated by comparison with other steamers of the time. The *Georgia*, a 76 m, 2,727 ton side-wheel steamer with two side-lever engines, consumed some 55 to 60 tons of coal per day at normal speed (Kemble 1943). The *Central America* was about the same size (approximately 83 m, 2,141 tons with two inclined engines) and presumably burned about 60 tons of coal per day. Engines were considerably more efficient by 1863, when William H. Webb launched the 106 m, 3,373 ton *Golden City* with a Novelty Iron Works vertical-beam engine. This side-wheel steamer used an average of 36.5 tons of coal per day on the Pacific Mail Steamship Company voyage from Panama to San Francisco in 1865, for a total of 485 tons for the entire trip (Kemble 1943). A large amount of space aboard these ships was occupied by the boiler coal. Since wooden ships, unlike steel vessels, had no ballast tanks which could be filled with seawater as the coal was burned, the vessel rode higher and higher out of the water as the voyage progressed. In rough seas, ships thus lightened would roll a great deal, bringing the paddle wheels out of the water, first on one side then the other. Auxiliary sails were used to lessen the rolling and trim the vessel.

Kemble (1943) cited engineer reports from early Panama Route steamers that claimed temperatures in excess of 56° C in the fireroom and bunkers. Many firemen and stokers were overcome by intense heat, requiring those who remained well to stand double watches. To solve this problem, William H. Webb and George W. Quintard designed an airtight fireroom for the *San Francisco*, with forced ventilation, instead of depending on hatchways with wind sails set above them to bring the air below. The *Central America* was constructed by the same shipbuilder and engine builder, and placed in service in October 1853, only two months before the *San Francisco* but it is not known whether or not she possessed these improvements. Since these improvements were first reported in the 22 December 1853 issue of the *New York Herald*, they may not have been incorporated in the design of the *Central America*.

Early Panama Route steamers used salt water in their boilers because they did not have condensers or sufficient tank capacity to carry fresh water for their boilers. The boilers had pipes designed for blowing out the salt residue that accumulated as the seawater was converted to steam but these pipes frequently clogged or otherwise became defective necessitating repairs at sea. A number of cubical iron water tanks (measuring about 2.0 m on a side) were observed at the wreck site of the *Central America* but these do not seem to be of sufficient volume to hold fresh water for the boilers and the needs of the hundreds of passengers and crew. Thus, it appears that the boilers on the *Central America* were charged with salt water. The *Orizaba*, built in New York by Jacob A. Westervelt in 1854, a 75-m steamer, was reported to have tanks for 68,000 l of fresh water as well as an icehouse with a capacity of 30 tons for passenger and crew needs (Ridgely-Nevitt 1981). The tanks found at the *Central America* wreck site would each hold about 7,500 l of water. Assuming a similar deployment on each vessel (adjusted for size differences), approximately 10 freshwater tanks were probably on board the *Central America*.

First Forty-Three Voyages

The *George Law*, named for the company director, was ordered by the United States Mail Steamship Company in February 1852 to service the Atlantic leg of the Panama Route between New York and San Francisco. The name was changed to *Central America* in July 1857, since George Law was no longer connected with the company (Kemble 1943). This company, incorporated in 1848, was organized to carry the mails between New York and the Isthmus by steamship. The fleet was started with two newly constructed vessels: the *Georgia*, built by Smith and Dimon in 1848 and the *Ohio*, built by Bishop and Simonson in 1848 (Table 3). The *Illinois*, also built by Smith and Dimon, was placed in service in 1851, followed by the *George Law* in 1853. Thereafter, the *George Law* or the *Illinois* maintained a bi-monthly service, sailing on the fifth and twentieth of each month from New York to Aspinwall. The two newer boats proved to be more satisfactory than the *Georgia* and *Ohio*, for the latter pair were laid up in 1854 (Ridgely-Nevitt 1944). Some tableware from the *Ohio* was apparently transferred to the *George Law*; a silver tray engraved with "Ohio" was recovered from the shipwreck site in 1991 (Artifact No. 34092).

The *George Law* was launched on 28 October 1852 and entered the New York - Aspinwall service on 20 October 1853. She was under the command of Capt. J. N. McGowan for the maiden voyage and for the next five round trips. The following officers were in command of the ship from 1853 to 1857:

Voyages 1-6:	Capt. John N. McGowan
Voyages 7-14:	Lt. Gustavus V. Fox, USN
Voyages 15, 16:	Lt. McKinstry, USN
Voyages 17-19:	Lt. Gustavus V. Fox, USN
Voyages 20-24:	Capt. Alfred G. Gray
Voyages 25-38:	Lt. William Lewis Herndon, USN
Voyage 39:	Lt. T. T. Hunter, USN
Voyages 40-44:	Cdr. William Lewis Herndon, USN

In contrast to the succession of commanding officers, George Ashby held the position of chief engineer throughout the life of the ship.

On her maiden voyage she stopped at Kingston, Jamaica for 20 hours to take on additional coal and arrived at the Isthmus on the morning of 31 October 1853. She sailed from Aspinwall on 1 November and arrived in New York on 10 November 1853 with 465 passengers and $872,831 in California gold (Ridgely-Nevitt 1944). The return passage was a stormy one. After leaving Havana, Cuba she encountered a near hurricane which raged along the entire Atlantic coast. There was fear for the ship's safety but she arrived in good condition (Heyl 1953).

The ship completed 43 rather uneventful voyages but achieved fame when she foundered a few days before completing her 44th round trip to Panama. A listing has been made of the New York departure and arrival dates, number of passengers on board and the value of the commercially shipped gold as reported by the *New-York Times* between October 1853 and September 1857 (Table 1). The number of passengers returning to New York generally ranged between 200 and 600 with only three instances beyond this range: 714, 737, and 817. During the first half of 1854, the *George Law* carried between $500,000 and $1,000,000 in gold every time she returned from Panama; thereafter, the cargoes normally exceeded $1,000,000 and twice they approached $2,000,000. During the final voyage 476 passengers were on board and a commercial gold shipment of slightly over $1,200,000 (in September 1857 pure gold was valued at $20.67 per troy ounce versus $381.40 in January 1995).

The details of the first 43 voyages were not well chronicled because they generally consisted of routine crossings. However, Kemble (1943) and Ridgely-Nevitt (1944) provided some details of voyage No. 16 (February 1855). When the *George Law* departed New York on 5 February, she carried a party of 16 invited guests of the Panama Railroad who planned to participate in the opening celebration of the rail line. They reportedly brought with them banners and fireworks. The start of the voyage was not a pleasant affair for some of the passengers as indicated by an article published in the *New York Herald* on 26 February 1855. The temperature was 24° F when the ship departed at 2:00 PM and the passengers huddled in their cabins looking for stoves but finding none. A small pipe containing steam from the boilers ran under the table in the dining saloon and warmed the feet of some. No dinner was served, only tea at 6:00 PM. Apparently conditions improved as the voyage progressed and on the morning of 15 February, the steamer entered the harbor at Aspinwall with the flag of New Granada at her fore and the Stars and Stripes on the mizzen. The invited guests and 457 regular passengers of the *George Law* left Aspinwall at 9:00 AM on the 16th in a train composed of nine passenger cars and one baggage car. The engine was gaily decorated with flags and the express car exhibited a profusion of streamers. Although the first train had crossed from north to south (Atlantic coast to Pacific coast) on 28 January, this crossing, "complete with flags, flowers, banquets and speeches," marked the first time the *George Law*'s passengers were transported entirely by rail across the Isthmus (Ridgely-Nevitt 1944).

The end of Lt. Herndon's first voyage (No. 25) was marked by a grounding in New York harbor at 8:00 PM on 29 November 1855, when the ship went ashore on a sand spit while under the command of a harbor pilot. On the ensuing flood tide the ship was extricated without incident. No damage was done but her "passengers and mails were brought on to the City by the steamer *Satellite*. The steamer *Leviathan* was at hand, and took the specie." (*New-York Daily Tribune*, 1 December 1855). Apparently the *George Law* did not require extensive service after it was floated off the shoal, for it maintained its normal schedule and departed for Panama again on 7 December.

During some voyages the *George Law* made the trip from Aspinwall to New York without stopping; at other times she touched at Havana or Kingston. At that time Havana was used as a way station for transshipping New Orleans-bound passengers to smaller United States Mail Steamship Company steamers, such as the *Empire City*. The cruise back to New York from Aspinwall generally took eight to ten days. In September 1856 (voyage No. 33), while Lt. Herndon, USN was commanding the ship, it was necessary to call at Key West after Spanish authorities in Havana refused permission for her to land (Ridgely-Nevitt 1944). Unfortunately, as the ship neared the Florida coast on 10 September, it was grounded on Pickle Reef but was soon extricated by the engineering crew (Coulter 1970).

Ridgely-Nevitt (1944) noted that after the sinking, a New York newspaper reported that the *George Law* had also been aground at the southern end of her route sometime in the spring of 1857. This is substantiated by dry-dock records at the Webb shipyard which show that after voyage No. 42 (June and July 1857), the hull was re-coppered and her engines and boilers were overhauled. It was the practice of shipbuilders at the time to attach copper sheathing to wooden hulls, particularly to those expected to do service in the tropics. This was to prevent fouling and colonization by various wood-boring creatures, specifically teredinid bivalves (shipworms). By that time, the *George Law* had seen 3 1/2 years of service on the Panama Route. Ocean-going steamers of the day had an expected useful life of about 10 years. It was also at this time that the ship's name was changed to *Central America*.

FINAL VOYAGE

The passengers and cargo that would eventually be aboard SS *Central America* during her final voyage started their journey in San Francisco by boarding the steamer *Sonora* (Fig. 12) on 20 August 1857, the same day that the SS *Central America* left New York for Panama. The *Sonora* carried some 500 passengers and an estimated six tons of California gold. Nearly half of this gold was a publicly reported commercial shipment that was placed in a locked strong room aboard the *Sonora*. The remainder of the gold, wealth acquired by miners and businessmen in California (*New York Herald*, 23 September 1857), was either given to the purser for safekeeping, or kept in their cabins, or on their person. This was the first leg of a voyage that would end in the disaster of the SS *Central America*.

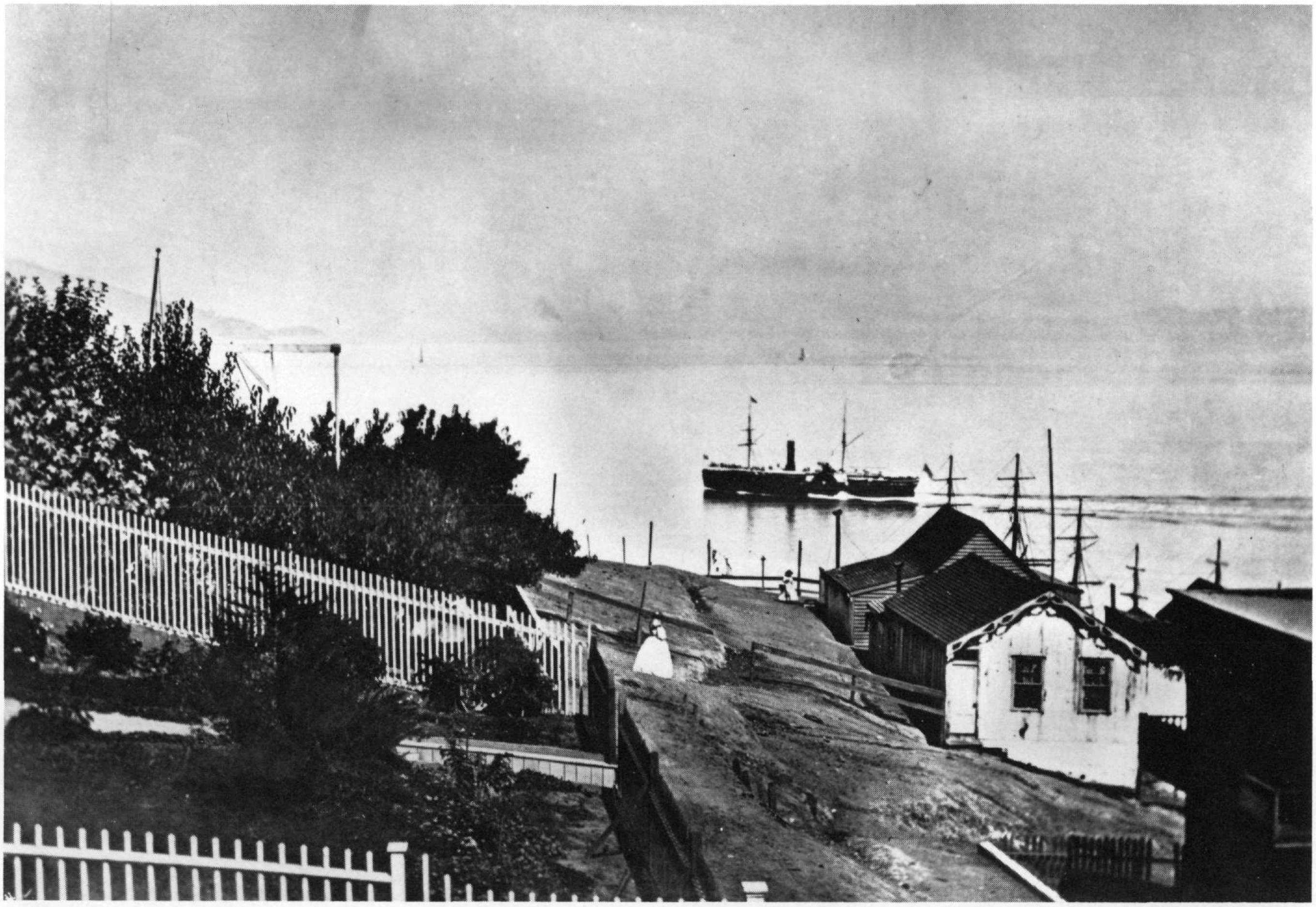

FIGURE 12. Photograph of SS *Sonora* (October 1862) taken from Telegraph Hill as the steamer departed San Francisco via the Golden Gate to the Pacific Ocean. Photograph courtesy of the National Maritime Museum, San Francisco and the Bancroft Library, University of California, Berkeley.

The *Sonora* was a wooden-hulled, side-wheel steamer with three decks and two masts. She was built for the Pacific Mail Steamship Company by J. A. Westervelt and Company in New York in 1853 and had a 82 m length, 11 m beam, 7 m depth of hold, and 1,617 tonnage. Her two vertical-beam engines (127 cm diameter cylinders with 3 m stroke) were built by Morgan Iron Works at a cost of $302,000. On her maiden voyage she cleared New York harbor on 11 March 1854, and arrived in San Francisco on 31 May, making the trip around Cape Horn. The *Sonora* was immediately placed in the San Francisco-Panama service and remained in it until May 1863. In 1868, she was found to be unseaworthy and was dismantled for parts at Sausalito, CA (Kemble 1943).

After a pleasant voyage of two weeks, the steamer *Sonora* arrived at the Pacific coast harbor of Panama City. The passengers and gold cargo were off-loaded for a four-hour train journey to the Atlantic coast harbor of Aspinwall (Fig. 13).

Start of the Voyage

On 3 September 1857, the steamer *Central America* waited in Aspinwall harbor for its California passengers and valuable cargo. The ship was under the command of Cdr. William Lewis Herndon, USN (Fig. 14). This was his 19th mission as captain of the *Central America*. Because this steamer carried U.S. Mail, government regulations stipulated that the vessel be under the command of a naval officer. The 43-year-old Virginia native headed a crew of 102, including officers, engineers, seamen, stokers, cooks, and stewards (Table 4). He was an able navigator and seaman who had distinguished himself as an explorer of the Amazon River basin.

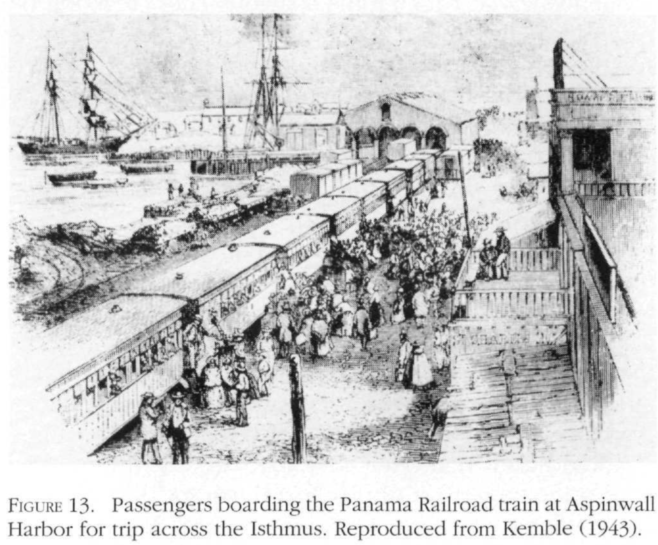

FIGURE 13. Passengers boarding the Panama Railroad train at Aspinwall Harbor for trip across the Isthmus. Reproduced from Kemble (1943).

FIGURE 14. Commander William Lewis Herndon, USN captain of the SS *Central America* during the final voyage. Photograph courtesy of U.S. Naval Academy Museum, Annapolis, MD.

Samuel Langhorne Clemens (author Mark Twain) later wrote that it was Herndon's book on the Amazon Expedition that instilled in himself the wanderlust that led to so many of his own adventures (Twain 1907, Allen 1954).

For the first few days out of Aspinwall en route to Havana, Cuba, the voyage was a pleasant one. The passengers enjoyed walking the spacious deck, relaxing on side-rail benches, and playing parlor games. The crew fed the engines coal at a rate of approximately 60 tons per day as the vessel steamed ahead at 11 knots. In Havana some additional cargo was taken on board, and under sunny skies the *Central America* headed northeastward through the Straits of Florida and then northward, pushed along by the Gulf Stream.

Several prominent California families were among the passengers. One couple, Ansel and Adeline Easton (Fig. 15), were on their honeymoon, en route to New York City and Paris. She was the former Adeline Mills, sister of the founder of the Bank of California, and he was a successful frontier entrepreneur. Rufus and Harriet Lockwood were traveling to New York with their three children. Rufus had been described as ". . . the greatest land title lawyer in California" (Hastings 1955) but he was somewhat eccentric because he had the unsettling habit of simply disappearing. Judge Alonzo Castle Monson was traveling back to his former home in New York City, having recently resigned his position on the bench of the 6th Judicial District Court of California. James Birch, who maintained a home in Swansea, MA, was traveling back to New England to visit his wife and young son. He had founded the California Stage Company,

TABLE 4

SS Central America
Officers and crew statistics for final voyage.

Category	Total on Board	Survivors
Captain	1	
Deck Officers		
First Officer	1	
Second Officer	1	1
Third Officer	1	
Purser	1	
Surgeon	1	
Boatswain	1	1
Engineers		
Chief Engineer	1	1
First Assistant Engineer	1	1
Second Assistant Engineer	1	1
Third Assistant Engineer	1	
Fourth Assistant Engineer	3	
Baker	1	
Barber	1	
Butcher	1	
Coal Passers	10	1
Coal Passers and/or Ashmen	3	
Cooks		
Ship's Cook	1	1
Second Ship's Cook	1	
Third Ship's Cook	1	
Saloon Cook	1	1
Second Saloon Cook	1	
Third Saloon Cook	1	
Pastry Cook	1	
Firemen	12	6
Mess Men		
Officers' Mess Man	1	
Firemen's Mess Man	1	
Pantrymen	3	
Porters	2	
Quartermasters and/or Seamen	5	5
Scullion	1	
Seamen	10	7
Seamen and/or Boys	2	
Servant (Captain's)	1	1
Silverman	1	
Steward	1	
Steward (Steerage)	1	
Stewardess	1	1
Storekeeper	1	
Storekeeper (Steward's Department)	1	
Tinman	1	
Waiters		
Head Waiter	1	
Waiters	12	1
Steerage Waiters	6	
Water Closet Boy	1	
Total Officers and Crew	102	29

FIGURE 15. Ansel Ives Easton and Adeline Mills Easton, First Cabin passengers on the final voyage of the SS *Central America*. Photographs courtesy of Mrs. Alice McCully.

the most prominent stage line of the Gold Rush years. He was carrying a silver cup intended as a present to his son from a family friend still in California. Billy Birch and his new bride Virginia were on their way to New York City where he was scheduled to perform as a singer and comedian with Bryant's Minstrels. Captain Thomas W. Badger was traveling with his wife Jane. He had been master of his own ship in San Francisco, the bark *Jane A. Falkinberg*. Mrs. Badger placed their fortune, $16,500 in gold coins, in a carpetbag when the seas became rough (*New-York Times*, 24 September 1857).

Classes of accommodations on board the *Central America* included First Cabin, Second Cabin, and Steerage. The First Cabin passengers enjoyed small but comfortable cabins appointed with china wash basins, water pitchers, and soap dishes. These cabins were located in the aft portion of the ship and ran along both the port and starboard sides of the main deck. Each cabin opened into the main saloon which contained a grand dining table that ran the entire length of the saloon. Second Cabin passengers had more modest accommodations located in the aft portion of the lower deck. Steerage, the lowest priced accommodation, was essentially a dormitory with racks of three-tier high bunks located forward on the main deck and lower deck (so named because the post for the steering rudder on earlier vessels protruded into this type of accommodation). There were 102 First Cabin, 48 Second Cabin, and 326 Steerage passengers on board the final voyage of the *Central America* (Table 5). The price of passenger tickets for the *Central America* in 1857 was: First Cabin–$300, Second Cabin–$250, Steerage–$150. In 1857 gold was valued at $20.57 per troy ounce, thus tickets cost 14.58, 12.15, and 7.29 ounces, respectively. At that time the average California miner made about $3 per day (Paul 1947), the salary of steamship captains was about $5 per day (Kemble 1943). A typical miner would have had to use the proceeds of 50 days work to purchase a Steerage ticket.

Storm and Sinking

After an overnight stop in Havana, Cuba, the *Central America* departed at 9:30 AM on 8 September for New York and proceeded northeast through the Straits of Florida and north following the Florida Current and the Gulf Stream. On 9 September the weather began to deteriorate and soon a tropical storm developed that would eventually reach hurricane proportions (Table 6).

Like Hurricane Hugo which devastated South Carolina in 1989, the tropical cyclone that has now become known as the *Central America* Hurricane (Herdendorf and Conrad 1991a) swept northwestward from the Caribbean. The ship was engulfed by the storm in September 1857, the day after leaving Havana. Winds approached 100 miles per hour as they rotated around a central low pressure area called the "eye." Little was known about the behavior of hurricanes in the 1850s and Capt. Herndon continued on his normal course; unknowingly, he was steaming on an intercept course with the hurricane's eye.

The *Central America* weathered the storm for two days but eventually the twisting of the hull resulted in several serious leaks. The rising water in the bilge threatened to wet the coal and quench the boilers. Obeying Capt. Herndon's order, a heroic effort was made by both passengers and crew, who bailed with buckets for

TABLE 5

SS Central America
Passenger and crew statistics for final voyage.

Category	Total on Board	Survivors
Passengers		
First Cabin		
Men (16 and older)	62	17
Women (16 and older)	19	19
Children (under 16)	21	20
	102	56
Second Cabin		
Men (16 and older)	40	2
Women (16 and older)	4	4
Children (under 16)	4	4
	48	10
Steerage		
Men (16 and older)	315	47
Women (16 and older)	7	7
Children (under 16)	4	4
	326	58
Total Passengers	476	124
Crew		
Men	101	28
Women	1	1
Total Crew	102	29
Totals: Men	518	94
Women	31	31
Children	29	28
Total Passengers and Crew	578	153

TABLE 6

SS Central America – *Disaster timeline – 1857.*

	THURSDAY, 20 AUGUST
9:00 AM:	The Pacific Mail Steamship *Sonora* leaves San Francisco for Panama with hundreds of passengers and a large shipment of gold bound for New York City.
	THURSDAY, 3 SEPTEMBER
Morning:	The *Sonora* docks at Panama. Passengers board the Panama Railroad for the brief trip to the Atlantic coast.
4:00 PM:	Passengers board the United States Mail Steamship Company steamer *Central America* and set course for Havana.
	MONDAY, 7 SEPTEMBER
Evening:	The *Central America* docks at Havana to transfer the few passengers and cargo destined for ports other than New York City.
	TUESDAY, 8 SEPTEMBER
9:30 AM:	The *Central America* departs Havana.
	WEDNESDAY, 9 SEPTEMBER
Evening:	Winds and seas increase as the *Central America* enters the fringes of a hurricane.
	FRIDAY, 11 SEPTEMBER
9:00 AM:	A leak is discovered as the steamship strains under the full force of the hurricane.
2:00 PM:	The fires in the boilers are extinguished by the rising water. The captain calls for every man to assist in bailing the ship. As the day progresses, all efforts are made to remedy the steamer's worsening condition.
	SATURDAY, 12 SEPTEMBER
8:00 AM:	Capt. Herndon concludes that his ship will sink unless the storm abates.
12:00 Noon:	A small sailing vessel, the brig *Marine* of Boston, sails into view. Lifeboats are lowered and all afternoon successive trips are made between the steamer and the brig to rescue the women and children first and then some of the male passengers and crew.
6:30 PM:	The schooner *El Dorado* sails near the *Central America* but is unable to rescue anyone due to her crippled condition and lack of lifeboats.
8:00 PM:	The *Central America* sinks. Hundreds of men are cast upon the waves.
	SUNDAY, 13 SEPTEMBER
1:00 AM:	The Norwegian bark *Ellen* sails into the midst of men struggling in the water and, over the next eight hours, manages to rescue fifty of them.
12:00 Noon:	The search for additional survivors is discontinued. The *Ellen* and the *Marine* set sail for Norfolk, VA.
3:00 PM:	The *Ellen* hails the bark *Saxony*, bound for Savannah, GA, and transfers five survivors wishing to go there.
	TUESDAY, 15 SEPTEMBER
7:00 AM:	United States Mail Steamship Company steamer *Empire City* weathers the storm and anchors in quarantine zone 6 km from port of Norfolk, VA for repairs and coal.
Afternoon:	The *Ellen* sights the propeller *Thomas Swann* and requests a tow. The vessel has insufficient fuel to accommodate but offers to take passengers to Charleston, SC. No one accepts the offer.
	THURSDAY, 17 SEPTEMBER
	Captain of *Empire City* receives a dispatch from USMS headquarters that the *Central America* is overdue at New York and he prepares to proceed to sea and search for the *Central America*.
Evening:	The *Ellen* enters Norfolk Harbor, VA, and anchors offshore.
Late Evening:	The *Thomas Swann* arrives in Charleston and the first word of the *Central America*'s sinking is telegraphed to New York City.
	FRIDAY, 18 SEPTEMBER
5:00 AM:	Five of the survivors on the *Ellen* engage a pilot boat to take them to Norfolk and en route they encounter the *Empire City* heading out to sea and tell of the disaster.
Morning:	New York City newspapers publish first news of the disaster.
	The *Empire City* steams to the *Ellen* and takes on board many of the survivors and then proceeds toward Cape Henry in search of the *Marine*.
Afternoon:	The *Empire City* finds the *Marine* in tow of the propeller *City of Norfolk* and takes on board most of the survivors. The *Empire City* sails for New York City.
	The *Saxony* arrives in Savannah with five survivors.
	SUNDAY, 20 SEPTEMBER
10:00 AM:	Survivors aboard the *Empire City* arrive in New York City.
	MONDAY, 21 SEPTEMBER
4:00 PM:	The last three survivors of the *Central America* disaster are rescued at sea by the British brig *Mary* after drifting hundreds of kilometers and enduring eight days and 20 hours of incredible suffering.
	MONDAY, 28 SEPTEMBER
12:00 Noon:	The Bremen bark *Laura* hails the *Mary* and takes the three survivors on board.
	MONDAY, 5 OCTOBER
Morning:	The last three survivors arrive at New York aboard the *Laura*.

30 hours in an attempt to keep the ship from sinking (Fig. 16). Fatigued from hours of bailing, the men were unable to keep up with the rising water and soon the boilers flooded.

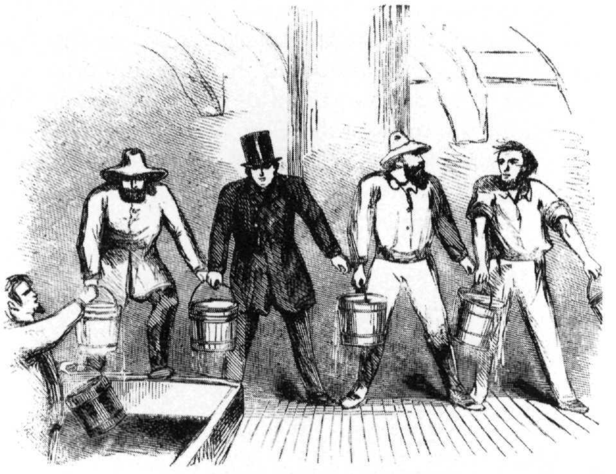

FIGURE 16. Passengers bailing the stricken ship during the hurricane. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

With her masts splintered and her rigging ravaged by the hurricane, the *Central America* was virtually destroyed, and on the early afternoon of 12 September she tossed in mountainous seas on the verge of sinking (Fig. 17). Miraculously, a small passing vessel, the brig *Marine* of Boston, managed to pull near the *Central America*. Although she too was crippled by the storm, her captain offered assistance. Three of the *Central America's* six lifeboats were lowered successfully. Captain Herndon ordered that all of the women and children were to be saved first (Fig. 18). The noble bailing effort of the men had bought enough time for the evacuation of all 31 women and 28 of the 29 children on board to the brig *Marine*. Jane Badger hoped to save her carpetbag filled with gold coins but she couldn't manage to carry the 28-kg weight from her cabin. Left with her husband, the gold was transformed to a useless fortune.

Captain Hiram Burt of the brig *Marine* attempted to keep his ship as close as possible to the *Central America* but by late afternoon he had drifted over a mile away. Even at this distance the rescue operation continued, with some passages between the ships taking over two hours, until the women and children and 41 men had been saved (Fig. 19). On board the *Marine,* Adeline Easton waited in vain for her husband to arrive, as did

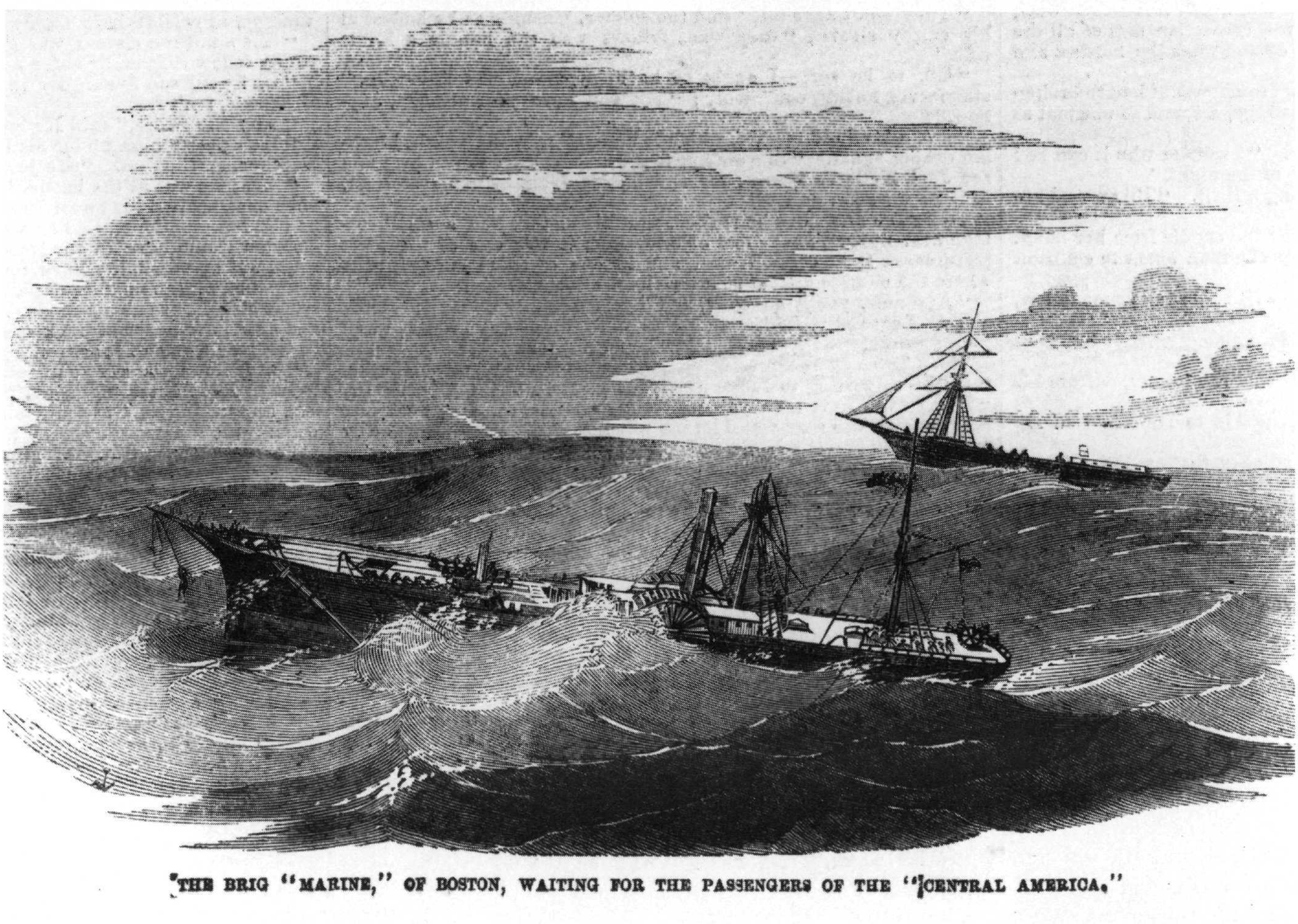

FIGURE 17. About eight hours before the sinking of the storm-battered *Central America*, the brig *Marine* arrives to save the women, children, and 41 men. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

FIGURE 18. A woman being lowered to a lifeboat. It took as long as two hours to row the lifeboats through the stormy seas between the *Central America* and the *Marine*. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

Harriet Lockwood, Virginia Birch, and Jane Badger for their respective husbands. None of them were aboard the last boat as darkness ended the rescue. Captain Herndon had sent a message to Captain Burt asking him "to lay close by him all night for God's sake, as he was in a sinking state, and had five hundred souls on board . . ." (*New-York Times*, 21 September 1857). The morning would be too late for the *Central America*.

Bailing continued until about 7:30 PM when it became obvious that the ship would soon sink. Life preservers were passed out and the men began to search in earnest for buoyant objects and rafts which would help them stay afloat. One large raft was constructed by cutting away the forward part of the hurricane deck. About this time Captain Herndon went to his state-room, put on his dress uniform, climbed to the top of the port wheelhouse, and fired rockets obliquely into the sea signifying that his vessel was sinking rapidly (Fig. 20). His final order was: "Buckle on your life preservers. We are going down." (Klare 1992). The tremendous weight of the useless engines, some 750 tons, dragged the ship down so that her uppermost deck was riding level with the sea. Almost every wave that broke over her swept men off her deck. Shortly after 8:00 PM the vessel gave three lurches from monstrous waves, the bow raised high into the air, and the ship sank stern first, going down at an angle of 45° (Fig. 21). Given the ship's characteristics, *Central America* collided with the ocean floor some 15 to 20 minutes later. The *Central America* sank in the North Atlantic Ocean near latitude 32° N and longitude 77° W where the sea was over 2 km deep. This location was east of the main track of the Gulf Stream in a part of the ocean known as the Sargasso Sea. Floating mats of the brown algae (*Sargassum*), which are common there, give the sea its name.

Nearly 500 men were thrown into the sea (Fig. 22). From the *Marine*, "Addie" Easton watched the lights go out on the *Central America* and knew that Ansel was lost. Because there were 600 to 700 tin and cork life preservers on board, it is probable that every person succeeded in getting one or more of them. But when the ship sank, the suction drew many of the men down, tearing off the preservers. Still, many survived the initial sinking by clinging to pieces of wreckage.

By incredible good fortune, at one o'clock in the morning of 13 September 1857, the Norwegian bark *Ellen* sailed into the midst of the men struggling in the water. Over the next eight hours 50 men were miraculously plucked from the water. Among those rescued were Ansel Easton, Billy Birch, and Thomas Badger. Captain Herndon may have been seen hanging onto a piece of plank during the night, but he was not rescued (*Richmond Daily Dispatch*, 30 September 1857). Rufus Lockwood was also lost at sea but his wife was reportedly so used to his mysterious disappearances that for years afterward she expected him to appear at her door (Hastings 1955).

Stagecoach entrepreneur James Birch may have been one of about a dozen men who floated away from the wreck on an improvised raft—a fragment of the steamer's hurricane deck. The next morning George Dawson, a stage line hotel employee, made his way to the raft (Fig. 23). Without food or fresh water, the men on the raft suffered immensely. One by one most of them died—some washed into the sea, others fell prey to exposure, exhaustion, or mental derangement. James Birch did not survive but before his death he passed his son's silver cup into George Dawson's care (Banning and Banning 1930). Some accounts have indicated that Birch may have given the cup to Dawson on board the *Central America* and that he may not have been on the raft at all (Klare 1992). In any event, by 17 September, five days after the *Central America* sank, only Dawson and Alexander Grant, a fireman from the ship's crew, remained alive on the raft. On that fifth day since the sinking, they saw one of the *Central America*'s lifeboats drifting at a distance. Grant swam to the battered lifeboat where he found John Tice, the steamer's second assistant engineer. Together the two rowed back to pick up Dawson (Fig. 24). By this time they had lost their sense of hunger but their thirst created indescribable tortures.

Finally, on 21 September, eight days and 20 hours

FIGURE 19. Drawing of the rescue ship *Marine* on the sheet music cover, THE MARINE REDOWA, circa November 1857. The redowa (a popular Bohemian ballroom dance of the nineteenth century) was "dedicated to the brave, energetic and whole souled Capt. Hiram Burt, of the brig *Marine* who rescued from a watery grave a large number of passengers of the ill-fated *Central America."* Published by Oliver Ditson & Co., Boston. Reproduction courtesy of Library of Congress. Washington, D.C.

CAPT. HERNDON ON THE WHEEL-HOUSE OF THE "CENTRAL AMERICA" FIRING A ROCKET.

FIGURE 20. Capt. Herndon firing a distress rocket from the wheelhouse of the *Central America*. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

after being cast adrift, the three were found, barely alive, by the British brig *Mary* (Fig. 25). According to Maury (1857), they had been transported more than 720 km northeast of the scene of the tragedy by the Gulf Stream. They were the last of the survivors; 425 others, including Captain Herndon, were lost. The Eastons were reunited in Norfolk, VA, on 18 September 1857. Billy Birch and Thomas Badger were also reunited with their wives but sadly 12 other wives who survived the sinking mourned the loss of their husbands. On 5 October, George Dawson arrived in New York City, and sometime later he presented the silver cup to James Birch's widow.

Analysis of the Sinking

Maury (1857), in discussing the cause of the sinking in a report issued by the U.S. National Observatory, stated: "... at midnight on the 9th it freshened to a gale, which continued to increase till the forenoon of Friday, September 11, when it blew with great violence from N.N.E. Up to this time the ship behaved admirably; nothing had occurred worthy of note, or in any way calculated to excite suspicions of her prowess, until the afternoon of that day, when it was discovered that she had sprung a leak. The sea was running high; the ship was very much heeled over on her starboard side, and laboring heavily; the leak was so large, that by 1:00 PM the water had risen high enough to extinguish the fires on one side, and stop the engine. Bailing gangs were set to work—the passengers cheerfully assisting—and all hands were sent over on the windward side to trim ship. Being relieved, in a measure, she righted, and the fires were relighted. But there was a very heavy sea on, and, in spite of the pumps and bailing gangs with their buckets, whips, and barrels, the water gained upon them, until it reached the furnaces and extinguished the fires again, never to be rekindled ... The ship was now at the mercy of the waves, and was wallowing in the trough of the sea like a log. She was a side-wheel steamer, with not a little top hamper, and therefore an ugly thing to manage in such a situation ... A rocket was set off, the ship fetched her last lurch ... she went down."

Kemble (1943), in his review of Panama Route steamers, concluded that the "blame for the *Central America*'s loss seemed to lie with the engine-room force rather than with any structural defect or weakness in the hull. The fires were allowed to go down, and the ship lost headway, falling into the trough of the sea, where she was literally beaten to pieces."

The following analysis of the events leading to the sinking of the SS *Central America* has largely been derived from the assessment of Ridgely-Nevitt (1944). At 9:00 AM on Friday 11 September 1857, the engine-room crew found that the ship was making considerable water and listing so far to the starboard that it was difficult to use wheelbarrows for passing coal from the aft bunkers to the boilers. Most of the ship's waiters were sent below to aid in passing coal by buckets and baskets. The location of the leak could not be determined because it was already covered by the rapidly rising water. The coal bunkers were soon flooded making it impossible for the men to work in them. As the main boiler pressure fell because of coal starvation, the smaller donkey boiler was fired. The main engines stopped at about 1:00 PM. The crew was able to fire the port furnace of one boiler and the pressure was again built up. However, by 2:00 PM all starboard fires were extinguished and about 5:00 PM all the main boiler fires were quenched. The Worthington Pump was then shifted to the donkey boiler (steam was maintained by burning wood in the grates) but the feed pipe to the donkey boiler eventually clogged and had to be cut away and replaced. Gangs of bailers continued their work even though the list to the starboard increased and maintaining footing on the decks became more difficult.

The foreyard was lowered, the foresail clues were lashed to the deck, and the sails were set by hoisting the yard but the canvas was soon blown to shreds. Around 6:00 PM, the foremast was cut away in an attempt to right the ship but part of the rigging fouled one anchor and the cathead, causing the mast to shoot underneath the ship as it fell and may have further damaged the ship's bottom. The starboard anchor and chain were cut loose. A final attempt was made to head the ship into the wind by rigging a drag, consisting of the foreyard, a kedge anchor, and a hawser, which was made fast around the stump of the foremast. About 10:00 PM the hawser holding

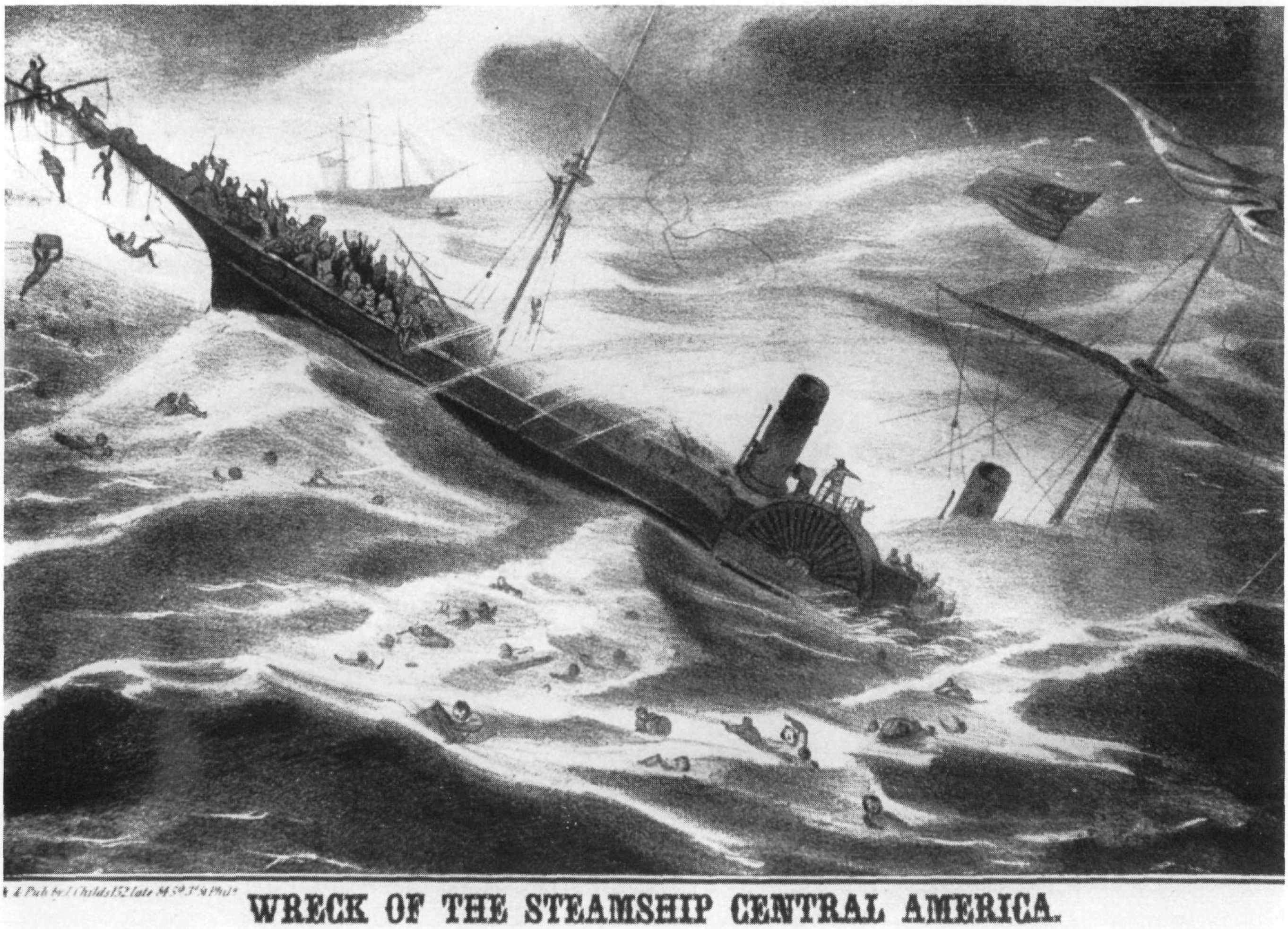

FIGURE 21. Sinking of the SS *Central America* shortly after 8:00 PM on 12 September 1857. Lithograph of the scene published in 1857 by J. Childs, Philadelphia. Reproduction courtesy of The Mariners' Museum, Newport News, VA.

the drag chafed through. The rocking of the ship opened a leak around the starboard wheel shaft which had settled about 15 cm, allowing water to gush in. This suggested a weakness in the linkage with the rest of the engine mechanism. The leak was plugged from the inside with blankets and sail canvas was wrapped around the wheel shaft.

At dawn on Saturday, 12 September the exhausted crew and passengers continued to bail and the steam pumps, although almost submerged, were still working. The crew cut off part of the main engine escape pipe and improvised a pair of hand pumps set up in the steerage compartment. Deadlights (porthole covers) along the ship's sides began to give way and had to be stuffed with blankets. Finally, about 9:00 AM the steam pipes became completely submerged and stopped. Of the six lifeboats that were on the *Central America*, one had been stove in during the night and two others were wrecked while being lowered or shortly after. Three were successfully launched and used to carry 100 passengers and crew to the brig *Marine* during the afternoon. Bailing continued until around 7:30 PM and the forward part of the hurricane deck was cut away to form a raft. The *Central America* sank shortly after 8:00 PM. Ridgely-Nevitt (1944) concluded that "the foundering of the *Central America* can best be laid to the inherent structural weakness of a wooden ship so twisted and torn by wind and sea that some part of the water-tight shell gave way."

Profiles of Officers, Crew, and Passengers

Historical research has yielded detailed biographical information about many of the individuals associated with the SS *Central America* disaster. Presented here is a selection of profiles of deck and engineering officers, various crew positions, and First Cabin, Second Cabin, and Steerage passengers. The commanding officers of the rescuing vessels, *Marine*, *Ellen*, and *Empire City* are also included as well as the captain of the schooner *El Dorado* and the chairman of an underwriters investigating committee. These profiles provide insights into the personalities and characters of the individuals involved in the tragedy and establish a historical context for interpreting the cultural artifacts found at the shipwreck site. A complete list of the passengers and crew for the final voyage is presented by Klare (1992).

Cdr. William Lewis Herndon, USN – Captain. Cdr. Herndon (Fig. 14) was born in Fredericksburg, VA on 25 October 1813, and entered the U.S. Navy in 1828. He served during the Mexican-American War and also

FIGURE 22. Men in the sea after the sinking of the *Central America*, drawn from a sketch by one of the rescued passengers. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

served for three years at the Naval Observatory and Hydrographic Office in Washington, DC. There he worked with his brother-in-law, Lt. Matthew Fontaine Maury, who was the director of the observatory, and who later became known as "the father of modern oceanography." Maury was best known for his oceanic wind and current charts, which revolutionized navigation and shipping (Maury 1855). Herndon worked with him on this monumental project. During the years 1851 to 52 Herndon was given a special assignment: to explore the valley of the Amazon River. The results of his study were first presented to Congress, and were then published in a

FIGURE 23. A raft, part of the *Central America*'s hurricane deck, carries the "living, the dead and the dying" away from the site of the sinking. George Dawson (left) reaches the raft but is not permitted to get on it. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 17 October 1857.

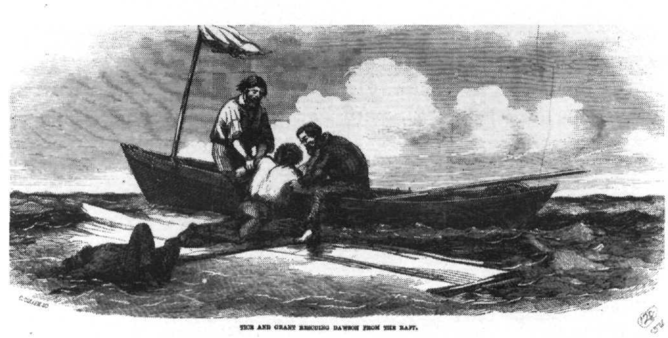

FIGURE 24. Grant and Tice rescue Dawson from the raft five days after the sinking. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 17 October 1857.


FRANK LESLIE'S ILLUSTRATED NEWSPAPER

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ADVENTURES AND SUFFERINGS OF THREE SURVIVORS OF THE "GREAT WRECK."

THEIR INDIVIDUAL NARRATIVES.

EIGHT DAYS AND TWENTY HOURS WITHOUT FOOD OR DRINK!

As if to make the horrors by shipwreck of the Central America in every particular the most unparalleled disaster that ever occurred on the sea, we have the details of the dread tragedy of some few of the passengers, whose sad story is heralded to the world by the means of three of the number, after suffering beyond what has heretofore been deemed possible by human nature and life be preserved.

Determined to do justice to the subject as far as it is in our power, we have brought all our comprehensive artistic and editorial facilities to bear, and our success has been beyond our most sanguine anticipations. We have secured the photographs of the three survivors, which will be found on an outside page; and in addition to this, we present thirteen designs illustrating the subject matter, made under the direction of the survivors, and exhibiting a series of faithful pictures such as were never before given to the public. In addition to this, we present full and complete narratives of the three survivors, which include some of the most thrilling and startling incidents ever recorded, and which will give to the world a new idea of the horrors of shipwreck, and in which will be found many things that have heretofore escaped the industry of the press. We would say, in justice to our readers, that we give much from narratives obtained from the lips of those whose sad stories we relate, we learned from personal interviews what were their sufferings, and were made to feel what they had endured. To them and to Capt. Burt of the brig Marine we are under many obligations, and we have no doubt the public will appreciate their willingness to gratify a just curiosity, and our determination to sustain an unrivalled position of the only illustrated newspaper in the country. In carrying out our plan, we deem it best to commence with the narrative of John Tice, one of the three survivors rescued and brought into the port of New York by the Laura.

Mr. Tice was one of the most active persons on board of the Central America in his efforts to save the ship. Finding, however, that the case was desperate, he took himself to the deck, and looked about for the purpose of securing such means as would probably save his life after the long dreaded catastrophe had taken place. Among the wrecks of the upper works which had been torn off by the passengers to make rafts, he found a plank ten feet long and about an inch and a half in thickness, and with it silently and resolutely took his stand upon the hurricane deck. In a moment the stern began rapidly to sink, and watching his opportunity, he anticipated his engulfment by seizing his plank and springing as far as possible from the ship into the sea, striking out, and when about forty feet distant, he saw the waves just closing over the fated vessel.

Fortunately he was far enough from the "suck" of the sinking

(Continued on page 317.)

FIGURE 25. The final rescue of Grant, Tice, and Dawson by the British brig *Mary* after nearly nine days of suffering in a lifeboat and on a raft. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 17 October 1857.

highly readable, illustrated book entitled *Exploration of the Valley of the Amazon*, which became very popular with the public (Herndon and Gibbon 1853, 1854).

During the terrible hours before the sinking of the *Central America*, Cdr. Herndon demonstrated a nobility and courage which made him a national hero. He was commended throughout the country for his orderly rescue of the women and children and his maintenance of discipline on board the ship—as well as for his personal courage in remaining with his ship to the last. From the survivors he received praise:

> "Capt. Herndon behaved nobly throughout, and was standing near me on the hurricane deck when she went down. He sank, however to rise no more, leaving a name honored among the heroes of the sea." (Oliver P. Manlove, *Charleston Courier*, 23 September 1857).

> "He was a noble man, and I shall never forget him as long as I live . . . The captain's kindness to me, and to all the ladies, was unremitting, and in the end he sacrificed his life for us." (Jane Harris, *New-York Daily Tribune*, 21 September 1857).

> "While they were getting into the boats there was the utmost coolness and self-control among the passengers . . . Capt. Herndon gave orders that none but the ladies and children should get into the boats, and he was obeyed to the letter." (Frank Jones, *New-York Daily Tribune*, 21 September 1857).

> "Captain Herndon . . . expressed his determination not to leave the ship while there was a soul on board, but would remain until she sank from under him. His only regret was his family—and he died like a brave man." (Thomas Badger, *New York Journal of Commerce*, 21 September 1857).

> "He deserved a better fate. I believe there was not a man left on board the ship but would have given his life if it could have saved the Captain." (Thomas McNeish, *New-York Times*, 21 September 1857).

Some of the survivors, however, were critical of Herndon. Passenger Joseph Bassford, in his account, stated that, "Justice compels it to be said that Captain Herndon, with all his nobility and disinterestedness of character, and notwithstanding his possessing in a high degree most of the traits necessary to an efficient commander, was not equal to the present trying emergency. He ran all over the ship, running here and there himself for a blanket, or a hammer, or trivial things which he should have sent others for. He was not wanting in manly courage, but he wanted decisive promptness. Had he subdivided matters properly, and exercised the rigidness of control necessary to the occasion, I think the steamship might have been kept afloat longer than she was, and possibly saved." (*New York Herald*, 21 September 1857).

In general, however, the nation's opinion of Cdr. Herndon's behavior was extremely positive. This was exemplified by an editorial in *Harper's Weekly* (26 September 1857): "Such a man does not die too soon for himself, but only for those who love him. The thought of his fidelity cheers even the gloom of that disaster. It is not hard to believe that in those dark hours his calmness made the doomed ones calm; that he died as heroes die, doing his duty; and that death came to him, as it comes to all Christian gentlemen, conquered, and not a conqueror."

Steerage passenger Adolph Frederick reported seeing Captain Herndon between two and three hours after the *Central America* sank: "Captain Herndon was provided with a handsome India rubber life-preserver, and was floating on a piece of plank . . . [he] seemed capable of floating for some time . . . [he] addressed them encouragingly, saying: 'Boys, this is a poor craft to get to New York in. Have you got any brandy among you?'" (*Richmond Daily Dispatch*, 30 September 1857). Both Lt. Dement and Henry Childs also reported seeing Captain Herndon about midnight (*Baltimore Sun*, 23 September 1857).

Cdr. Herndon was survived by his wife, Frances Hansbrough Herndon, and one daughter, Ellen Lewis Herndon—who later became the wife of General Chester A. Arthur. She died, however, before he became president.

James M. Frazer – Second Officer. James Frazer was 27 years old and 5'9" tall. His salary on the *Central America* was $40 per month. In his account, Captain Badger says, "Captain [Herndon] behaved nobly, and said he would not leave the ship. I promised him I would remain with him, as also did the second officer, Mr. Frazer." (*New York Herald*, 20 September 1857).

Second Officer Frazer described the events of the day before the sinking (Friday, 11 September 1857) as follows: "At about 10 o'clock A.M. the third officer set the storm spencer or spanker, and kept it on her until the sail blew to pieces. He also sent down the foreyard. The gale and sea were now increasing. He also spread canvas, bolts, sails, &c., in the main and mizzen rigging, but to no purpose, as the ship was so high out of the water that she would not head to the wind and sea." In the late afternoon, "the ship still in the trough of the sea. The captain then ordered us to cut away the foremast and see if that would help to right the ship. She was then listed over to the leeward, so that people could not walk the deck. I may say that she was almost on her beam ends. Myself, the boatswain, and Capt. Badger, a passenger, cut away the rigging and let the foremast go over the side. In going over, the rigging caught foul of the cathead and anchor, which caused the foremast to shoot under the ship's bottom, forward of where the foremast had been standing. I do not doubt that when the foremast went under the ship's bottom, she was injured by it, and probably the leak increased thereby. I don't know such to be the fact, but she thumped there some time. After the foremast was cut away we paid out the hawser that was attached to the drag to about ninety fathoms in all, giving it a turn about the stump of the foremast. This had no effect on the ship." (*New-York Times*, 22 September 1857).

Like all ship's officers, Frazer was on constant duty during the storm, and consequently was so exhausted that he was fortunate to have survived his hours in the sea. "He is very thin, and appeared to be quite feverish. He was nearly broken down . . . He was unconscious when he was picked up, after being in the water for six hours . . . For some time it was not expected that he would recover." (*New York Herald*, 21 September 1857). He was rescued by the *Ellen* along with Dr. Obed Harvey.

Coulter (1970) noted that the principal salvage company at the time of the sinking was the Boston Submarine Armor Company and it was rumored that it was negotiating with the insurers of the treasure on the *Central America*. In this regard, Second Officer Frazer said that the ship sank in ". . . six hundred fathoms of water . . . very remote that her hull will ever be discovered, or that any known method of reaching the submerged vessel will succeed in recovering her treasure." He added that the insurers of the treasure would doubtless sell their claims at a "low figure." (*New-York Times*, 28 September 1857).

James Frazer and his wife moved from New York to Portland, OR, in 1858, where he became second officer of the *Shubrick*, the first lighthouse tender on the Pacific Coast. James had a son, Herndon Frazer, named after Captain Herndon, and a daughter, who became Mrs. George D. Messagee. Her son was named Herndon Messagee (*Oregon Journal*, 10 August 1938).

Edward W. Hull and William H. Hull – Purser and Storekeeper. The Hull brothers were sons of the late David Hull, a printer in New York City. Edward was 32 and William was 26. Edward Hull and his wife, Mary Elizabeth, and two children lived in Brooklyn. He had formerly been a clerk in the firm of Howard and Sons, and had been a Purser on Panama steamers since they first went into operation. He served on the *Empire City* in 1851. He was commended for the precision and completeness of the reports he had always given them (*New York Herald*, 19 September 1857). Both of the Hull brothers were lost in the sinking.

The purser's cabin was located on the port side of the weather deck abeam of the aft portion of the paddle wheel. Equipment believed to have once been in the purser's cabin was recorded on the seafloor near the port side wheel.

John Black – Boatswain. John Black was 33 years old and 5'8" tall. His salary on the *Central America* was $30 a month. He was in charge of one of the lifeboats carrying passengers to the brig *Marine*. His was the last boat to return to the *Central America* and he was a witness to the sinking: "Left the brig on my third trip back to the steamer about 7 o'clock PM. Reached the steamer a few minutes before 8 o'clock. Was hailed by Capt. Herndon and Mr. Frazer, Second Officer. Told them the boat was stove and leaking, and Capt. Herndon told me to keep off about a hundred yards. Did so until the steamer sunk. Saw the last rocket fired horizontally, and fifteen minutes later the ship went down, amid the cries of all on board." (*New-York Times*, 22 September 1857).

Passenger Frank Jones said: "I met Black afterward on board the brig, and he said that he could not save any of the passengers on the last trip, as his men would not row up among the drowning people, fearing they would swamp the boat." (*New-York Daily Tribune*, 21 September 1857).

George E. Ashby – Chief Engineer. George Ashby was 35 years old and 5'10" tall. His salary on the *Central America* was $125 per month. He was a bachelor, supporting his mother and sister in New York. Many of the survivors place the blame for the *Central America* disaster on George Ashby. A leak was discovered in the engine room and the water came in much faster than Ashby anticipated. The water soon overflowed the coal burners, making it impossible for the men to pass the coal, and the boiler fires went out from lack of fuel. With no fire in the boilers, the engines soon stopped. The bilge pumps, which were also operated by the engines, also stopped. With her engines dead and her hull slowly filling with water, the *Central America* drifted helplessly in the hurricane. Many survivors chose to blame George Ashby for the problems in the engine room and believed that it was his inefficiency or incompetence that directly led to the sinking of the ship. Ashby was also accused of deserting the sinking ship and the passengers told widely varying versions of the episode. He took command of one of the lifeboats going to the *Marine*—either at Captain Herndon's direct order, or directly against his wishes. In the lifeboat, Ashby drew a knife to keep people from leaping from the steamer into the boat, and may or may not have threatened various passengers with it. Once on the *Marine,* Ashby either did, or did not, attempt to return to the *Central America* to rescue more passengers.

Passenger Oliver P. Manlove was one of the passengers who believed that Ashby was at fault, as his statement in the *Charleston Courier* (23 September 1857) illustrates: "The conduct of the engineer is much censured by all the passengers. I believe that better discipline in the engine room would have prevented the fires from going out and the steam getting down so low as to stop the working of the machinery and the pumps." According to Amanda Marvin, however, "Mr. Ashby was disposed to do his duty from first to last, and the opinions already expressed as to his conduct have in most cases been too harsh and altogether undeserved . . . [Ashby] was not especially gentle or refined in his use of terms, whether addressed to passengers or crew; but this . . . was the current language employed on board the ship." (*New-York Times,* 23 September 1857). Almira Kittredge agreed that while Ashby was indeed rough around the edges, his intentions were good: "On Friday night Mr. Ashby came down to the cabin, and pulled men out of their staterooms. They refused to go to work. He said they should go or he would throw them overboard . . . He said that he had a mother in New York, and was as anxious to see her again as any one could be to see his mother, and the only way to be saved to see them was to keep the bailing active." (*New York Herald,* 27 September 1857).

In regard to the accusations of desertion, Ashby explained his behavior in this way: "I said to [Captain Herndon] that, if I could be of service in any manner, I was at his disposal. He then asked me to go in the next boat . . . and to do all in my power to induce the captain of the brig to bring his vessel near to the steamer." (*New York Herald,* 22 September 1857). Passenger Joseph Bassford, however, described the scene in this way: "Ashby, the chief engineer, made a move to get into the boat. Captain Herndon told him not to get in. Upon which, Ashby besought the captain to place him in charge of the boat. He promised the captain that he would come back with the boat, and what was more, prevail on the captain of the *Marine* to come up with his vessel to where the steamer lay, and get him to send his small boats out. Captain H. said that he feared to trust him, as he was afraid that he would not come back. Upon this expression of doubt relative to himself, Ashby said–'I promise you, Captain, most solemnly, that I will come back to the steamer and not desert her.'" (*New York Herald,* 21 September 1857).

Passenger Henry T. O'Connor, 17, told a rather bizarre story concerning Ashby's behavior: "While the chief engineer was on board of the steamer he drew his bowie knife on me and attempted to cut away my life preserver, but someone interfered, by seizing his arm, and would not allow him to do it. After getting into the boat he threatened to stab any man who would jump aboard. This was as he was leaving the steamer. One man jumped into the boat after he made this threat, and he drew his bowie knife on him and had him by the throat, brandishing this weapon up and down, when a man sprang upon him and grabbed his arm. After the chief engineer got on board the brig [*Marine*] they say he attempted to drive the men back into the boats, and chased one man all about the vessel with a drawn knife." (*New York Herald,* 21 September 1857).

Ashby said the following about his own conduct on the *Marine*: "I ordered the men in the boat to take me to the steamer, and save as many lives as possible, but they utterly refused. Capt. Burt also tried to make them return to their duty, but without avail. I was, therefore, left powerless, and was compelled to remain in the brig." (*New-York Daily Tribune,* 22 September 1857).

Mrs. Marvin continued her defense of Ashby: "After placing his precious load safe on board the *Marine,* [Ashby] found only one of the sailors willing to return to rescue more of the passengers. The other three flatly refused to again venture on the waves, and none of the passengers (which is greatly to their discredit) would consent to take their places. Mr. Ashby entreated, saying, 'For God's sake come and help save more of the poor men. If two men will go back with me I will go back . . .' Under these circumstances Mr. Ashby was compelled to give over any attempt to save more of the people still on board the steamer." (*New-York Times,* 23 September 1857). Passenger Frank Jones confirmed Mrs. Marvin's statement, saying: "I heard Mr. Ashby implore the men who manned his boat most earnestly to return with him to the aid of the *Central America.* He offered them $100 apiece to do so, and attempted to throw some of them by main force into his boat, but all to no purpose." (*New-York Times,* 22 September 1857).

Ashby ended his own statement to the press as follows: "I know that I did my duty, upon the terrible occasion. It was God's will that the ship should be lost, and none of us had the power to prevent it." (*Daily Constitutionalist,* Augusta, GA, 22 September 1857).

An investigation by the New York Board of Underwriters following the disaster (Perry et al. 1857) vindicated the actions of George Ashby in leaving the sinking ship, and his certificates, which had been withheld pending the investigation, were returned to him. The Board's inspectors refrained from comment as to the causes leading to the disaster because their mandate was confined to inquires on the conduct of licensed officers. Ashby was not able to find another position as a chief engineer and in 1859 he entered the U.S. Navy as an assistant engineer and served aboard the steam gunboat *Mahaska* during the Civil War (Klare 1992).

John Lee Tice – First Assistant Engineer. John Tice from Newburgh, NY, was 27 years old, 5'6" tall, and single. He was described as "a small sized but hardy looking man, [who] appears to possess much energy and determination." As the ship was sinking he sprang overboard on a plank as the deck sank near to the surface: "I left the ship on a board just as she went down. I had no life preserver, and had no time to get one . . . when about forty feet distant, he saw the waves closing over the bow. He was sufficiently remote from the steamship when she sank, so that he was not carried under. In a moment the boiling surface of the sea was filled with the debris of the wreck, and grasping for them were scores of human beings, still hoping that they might yet be rescued from an impending fate." (*New-York Daily Tribune*, 6 October 1857).

"The last object I saw was Captain Herndon as the ship was sinking. I have no doubt that he perished. I drifted away from the others almost immediately, and was three days on the board, expecting every moment to be my last. On the third day I fell in with a boat which was about half full of water. I swam to it, got in with great difficulty, and succeeded in bailing out the water. I was two days in the boat when I fell in with a portion of the hurricane deck, and two men, Grant and Dawson, succeeded in getting into the boat with me. The others all perished. We floated around until the ninth day, when we were picked up by the brig *Mary*—all that time we had nothing to eat, and not a drop of fresh water. Most of the time the sea was breaking over the boat. We suffered everything but death. No man could describe what we endured. I think the chief engineer did his duty. I know nothing to the contrary." (*New-York Daily Tribune*, 6 October 1857).

Mr. Tice survived the sinking of the *Central America* only to die 21 years later in the sinking of another steamship. He was chief engineer of the steamship *Emily B. Souder* when it sank in December 1878.

David Raymond – Quartermaster. David Raymond was a hero of the disaster. He was in charge of one of the boats, the Captain's gig, that carried survivors to the brig *Marine*. He remained with his lifeboat even after the crew had refused to return to the steamer for a fourth time. Seaman James Travis described the last trip to the brig: "On our return to the *Central America*, [Seaman] Brown and myself gave up, as we were overcome with our labors both on board and in the boat. The quartermaster [Raymond] told us to lay on one oar, and both of us managed to man it. It took us two and a half hours to reach the steamer, this third time. When we did get alongside the boat was jammed against the side of the ship and had a portion of her gunwale knocked off and some of her timbers started. She then began to leak, and we had to get ten men to work to bail her out. Just then five passengers and three firemen jumped from the steamer into the boat, and Captain Herndon called to us to shove off, or the boat would be swamped." (*Richmond Daily Dispatch*, 22 September 1857).

On 9 November 1857, Quartermaster Raymond was recognized for his bravery with a medal presented by the *Central America* Relief Fund Committee, in token of their "appreciation for his humane and successful efforts toward saving the lives of those unfortunates cast adrift upon the ocean by the foundering steamer, *Central America*." In 1915, his widow donated the medal, an oil painting of David Raymond, and a water color of "The Wrecking of the SS *Central America*" by W. H. Hilton to the M. H. DeYoung Museum in San Francisco (Accession Nos. 415504, 41500 and 41511, respectively).

Alexander Grant – Fireman. Grant was about 25 and married with one child. He was 5'9" tall, muscular, and his salary on board the *Central America* was $35 per month. He was rescued by the British brig *Mary* after nine days at sea.

This was Grant's fourth shipwreck. He was on the brig *Atlas*, which foundered at sea 100 miles from Boston, as well as the *Crescent City*, which sank in December 1855. On the *Crescent City* he was a shipmate of George Dawson—who, by coincidence, was also on the *Central America* and was rescued by the brig *Mary*. Grant was also on the infamous *Arctic*, when it sank in September 1854 (350 lives were lost when panic-stricken men swamped the lifeboats). At that time he was in the water 52 hours before being rescued.

The *New York Journal of Commerce* has this to say about the appearance of Grant and his fellow survivor John Tice: "The physical description of Messrs. Tice and Grant exhibits signs of the terrible suffering endured during their nine days' exposure. Both are very weak and reduced in flesh—their feet are swollen, and on their lips, face, and hands are traces of sores, where the skin had been peeled off by the action of the salt water and their exposure to the scorching sun." In the same issue, Grant said, "I do not like to speak about our sufferings. They were all but death." (5 October 1857).

Lucy Dawson – Stewardess. At 56, Lucy Dawson was the oldest member of the ship's crew, and one of the oldest persons on the voyage (First Cabin passenger Albert Priest was 60 and Steerage passenger Daniel Beaver was also 56). Lucy was black, 5'6" tall, and her salary was $20 per month. She was rescued with the other women by the brig *Marine*, but died on the way to Norfolk, VA. She was buried on Craney Island in Norfolk. Passenger Jane Harris described the incident: "The stewardess of the *Central America*, who was taken off in the same boat that I was, fell into the water three times before she could be got on board. She mentioned to me that she was hurt between the life-boat and the brig while she was in the water. A wave dashed the small boat against the large one, and she was between them . . . Lucy died . . . I think her death occurred the next day. She was a bright, active woman, and was very much esteemed by the passengers." (*New-York Daily Tribune*, 21 September 1857).

Capt. Thomas W. and Jane Badger – First Cabin Passengers. Captain Badger (Fig. 26) was 30 years old at the time of the *Central America* disaster and his wife Jane was 22. He was captain of the San Francisco-based bark *Jane A. Falkinberg*, which regularly sailed between San Francisco and Oregon. He arrived in San Francisco in 1849. Captain and Mrs. Badger both survived the sinking of the *Central America*; only four couples were reunited after the disaster.

This was Captain Badger's third round trip on the *Central America*. He described Captain Herndon in the following terms: "[He] expressed his determination not to leave the ship while there was a soul on board, but would remain until she sank under him. His only regret was his family—and he died like a brave man." (*New York Journal of Commerce*, 21 September 1857).

Captain Badger was also a brave man who stood by Captain Herndon as the ship sank and assisted him throughout the tragedy. Passenger Oliver P. Manlove said: "[Capt. Badger] assisted in organizing the gangs for bailing, and cheered us all up with hope of ultimate safety until all hope was gone, and then gave us the aid

FIGURE 26. Capt. Thomas W. Badger, a passenger on board the *Central America* who assisted Capt. Herndon during the crisis and stood by his side as the ship sank. He was later saved by the Norwegian bark *Ellen* and reported an estimated location of the sinking. Reproduced from *San Francisco Chronicle*, 23 February 1896.

of his nautical experience in securing the best means of safety." (*Charleston Courier*, 23 September 1857).

Captain Badger witnessed the sinking: "The ship . . . sank, going down at an angle of 45 degrees, stern foremost. The suction of the ship drew the passengers under water for some distance, and three of them in a mass together. When they reached the surface the struggle for life was intense, with cries and shrieks for help, especially from those unable to swim. Many unable to swim clung to those who could, or laid hold of the larger pieces of the wreck, which were soon swamped." (*New York Journal of Commerce*, 21 September 1857).

In his account, Captain Anders Johnsen of the *Ellen* stated that: "Only two of the forty-nine [rescued by the *Ellen*] were able to be of any service rescuing others or ministering to those who had been rescued. Those two were Captain Badger and Mr. A. J. Easton [sic]." (*New York Herald*, 22 September 1857).

Captain Badger lost a large amount of treasure in the disaster. The *New-York Times* (23 September 1857) stated that he had $20,000 in gold pieces which his wife offered to take with her, in a carpetbag, to the brig *Marine*. [Note: The *New-York Times* of 24 September said $16,500]. Captain Badger, however, decided that the money must take its chances with him. Several newspaper accounts claim that Captain Badger was carrying the gold-filled carpetbag with him until the very end. Once he realized that the ship was sinking, however, he threw the carpetbag to the floor of his—or, in some accounts, Captain Herndon's stateroom (*New-York Daily Tribune*, 21 September 1857).

A trumpet ("loud hailer") which was presented to Captain Badger in token of his bravery is on display at the Eastern Shore of Virginia Historical Society, Inc., in Onacock, VA. The trumpet bears the following inscription: "Presented to Captain Thomas W. Badger by the *Central America* Fund Committee in token of their high appreciation of his conduct on board of the steamer *Central America* at the time of the loss of that ill-fated vessel. New York, May 17, 1858."

James E. Birch – First Cabin Passenger. James Birch was born on 30 November 1827 in Providence, RI. He arrived in California in 1849 as a member of an overland immigrant party and began operating a single wagon in Sacramento, carrying passengers to the gold fields. Business increased rapidly and in 1854, all major stage lines in northern California merged to become the California Stage Company with Birch as President (*Providence Post*, 21 September 1857). At the time of the sinking he was President of the San Antonio and San Diego Mail Line, which delivered mail between San Antonio, TX, and San Diego, CA. This was the western link of the first regularly scheduled transcontinental mail line in the U.S. Ironically, Birch never got to see the results of his great success because the first mail reached San Diego on 8 September 1857—while Birch was at sea on the *Central America*—just four days before his death when the steamer sank.

The San Francisco *Daily Evening Bulletin* (24 October 1857) commented on Birch's behavior just before the sinking: "Among the incidents demonstrating the coolness and courage of individuals may be mentioned the conduct of James E. Birch, ex-President of the California Stage Company. Seeing him without a life-preserver, a few minutes before the last plunge, Gabriel Brush, the baggage-master, an acquaintance, supplied one to him, and offered to buckle it around his waist. Birch refused—saying there was no chance to preserve life by such means—that he should perish from the cold—and that it would prolong his misery to float upon the water. He preferred to meet his fate at once—and professed his willingness to do so. Lighting another cigar, he turned aside—and was never seen after the steamer went down."

A remarkable story has been passed down concerning James Birch and fellow passenger George Dawson. Before leaving California, Birch received a silver cup from a friend as a gift for Birch's young son Frank. When Birch became despondent over his chances for survival, he called on his acquaintance George Dawson and entrusted the cup to him. Dawson was rescued by the *Mary* and after returning to New York, he located James Birch's widow Julia and presented the silver cup to her (Klare 1992). The silver cup is now on display at the Hearst Memorial Mining Building, the University of California, Berkeley.

The *Providence Daily Journal* (29 September 1857) reported that in another way Julia Birch was provided for by her husband's forethought: "It seems that Mrs. Birch—wife of Mr. James Birch, President of the California Stage Company, who was among the lost passengers of the *Central America*—was not left destitute by her husband. Mr. Birch sent on, in the *Illinois*, the steamer which preceded the *Central America*, $60,000 in gold bars, for which he also remitted a draft payable to the order of his wife. On Wednesday last Mrs. Birch sent the bars to the Assay Office in New York to be refined and stamped."

William and Virginia Birch – First Cabin Passengers. William "Billy" Birch was a famous minstrel comedian and singer, described as "the bright, particular star" of the San Francisco Minstrels (*Alta California*, 14 August

1857). He sang such songs as "The Grape Vine Twist" and "I'm Fatter than I Wish to Be" and starred in farces like *The Rival Tragedians* and *The Two Barnums of Connecticut.* A review stated: "The very sight of Billy Birch is enough to make a cynic laugh . . ." (*San Francisco Alta,* 26 October 1856). He was slight, bald, and had a soft mellow voice. At the time of the sinking he was 26 years old and on his way to New York to perform with Bryant's Minstrels of that city. He was born in Utica, NY.

Billy was on the *Central America* when it sank and was rescued by the *Ellen.* According to *Frank Leslie's Illustrated Newspaper* (3 October 1857), Billy continued to entertain even while clinging with a number of others to a floating hatch window after the *Central America* went down: "To keep up their spirits he mimicked the sea monsters, told humorous stories . . . bleeding from wounds, at midnight, tossed to and fro upon the angry waves of mid-ocean, he not only showed himself a true philosopher, but inspired courage in others, nor did he cease his vivifying harangue until an overwhelming billow choked his utterance." Concerning this incident, Billy said simply, "I tried to cheer those who were near me." (*New York Herald,* 20 September 1857).

Billy and Virginia Birch were married on 19 August 1857, the day before the sailing of the *Sonora. The New-York Daily Tribune* (21 September 1857) described Virginia: "Mrs. Birch is young, petite in form, and in personal appearance very attractive; added to this state she is possessed of a lively vivacity which renders her very interesting in conversation . . . In the cabin of the *Empire City,* [some of the survivors that were rescued by the *Marine* and *Ellen* were transferred to this steamer to complete the voyage to New York] Mrs. Birch was the object of general interest. The ready and intelligent manner in which she depicted the events connected with the disaster as they came under her notice, led her statements to be sought with avidity by reporters. She, like the other rescued passengers, with few exceptions, was but sparsely clad—none having more than three or four articles of apparel on their persons."

Virginia detailed her departure from the *Central America*: "I noticed the stopping of the engines of the steamer . . . I asked my husband, who was with me, what was the cause of it, and he presumed it meant nothing serious . . . The greatest solicitude that was felt at first by the ladies, particularly the married ones, was for their husbands at the pumps. I knew my husband was among the workers, and I knew from his spirit he would work as long as a particle of strength remained . . . I expected that it was the intention to transfer all the passengers to the brig, otherwise would not have left while my husband remained behind. But he told me to go and he would soon follow, and so I went." (*New York Herald,* 21 September 1857).

Virginia brought her pet canary, in its cage, with her on the voyage and she would not leave it behind to die: "The bright thought suggested itself to her to put it into her bosom, which she did . . . she carried the canary—her heart's treasure next to her 'Billy'—safely in its resting place until she reached the brig *Marine.*" (*New York Herald,* 21 September 1857). Virginia said of the incident, "The little fellow bears no marks of his late hardship, save that his feathers are disarranged from the effects of the bath." (*Baltimore American,* 22 September 1857).

Virginia and Billy Birch both survived the sinking of the *Central America*; only three other couples were reunited after the disaster (First Cabin passengers Thomas and Jane Badger, Ansel and Adeline Easton, and Steerage passengers Bernhard and Mary Seeger) (Fig. 27).

FIGURE 27. Reuniting of the Seeger family, steerage passengers, on board the steamer *Empire City* near Norfolk, VA. The Seegers were one of only four couples to be reunited after the sinking and they were the only family with children passengers to have the father also saved. Reproduced from *Frank Leslie's Illustrated Newspaper,* New York, 3 October 1857.

Robert Turnbull Brown – First Cabin Passenger. Robert Brown, 36, was a dry goods and clothing merchant who established his business in Sacramento in 1850. He and John Dement were the last two persons saved by the *Ellen* when Brown's friend Ansel Easton implored Capt. Johnsen to continue the search for survivors. Brown was apparently pleased with the performance of the *Central America* during the early stages of the storm: "The steamer behaved beautifully . . . there was a heavy and severe gale. I sat from 8 o'clock in the morning until 12 at noon, watching the progress of the storm. The steamer all the time had her head to the sea and acted handsomely, and never appeared to even strain, for there was no creaking noise of that character. The wind was very strong, but the sea was excessively high. At that time the vessel behaved so well that I made up my mind to wait two weeks for her at any subsequent time that I should wish to go to California. There was but one opinion on this subject held by all the fifty passengers saved on the *Ellen.* Capt. Badger said that he never saw a ship behave better. The only apprehension I felt was that her machinery might give out or become damaged . . ." (*New-York Daily Tribune,* 21 September 1857 and *Daily Alta California,* 23 October 1857).

Passenger Brown discussed the stopping of the engines: ". . . one of the engines—that on the starboard side—stopped, owing to the fire in its furnace going out. At 3 o'clock [Friday PM, 11 September 1857] the fire in the furnace on the larboard [port] side went out, and that engine, which had been working but slowly, also stopped. The reason was they could not get coal on account of the water which had come in. After the fires went out the steamer went into the trough of the sea." (*Milwaukee Daily Sentinel*, 24 September 1857). Brown was emphatic in his condemnation of chief engineer Ashby: "Among the rescued passengers there is but one opinion, and that is that the loss of the steamer is to be attributed to him in letting the fires go out." (*New-York Daily Tribune*, 21 September 1857).

Brown also commented on the encounter with the schooner *El Dorado* and the sinking: "About dark a schooner hove in sight, and passed on the starboard side; she was told our position by the captain. Her captain replied that 'he would lie by;' but on the contrary, they passed on, and we saw nothing more of them. She passed so quickly that we could not ascertain her. She was rather small, and clipper built, but of sufficient size to contained us all. At that time the storm was not very severe. We then had but one sail on our main-mast. The brig *Marine* was fast disappearing. She would have probably taken on board more passengers, but she was disabled in her sailing gear, so she could not control her motions, and had to run before the wind. We now perceived no hope of keeping afloat much longer, and nearly all prepared for the worst by procuring life-preservers and floating materials. Three rockets were discharged, and just after a heavy sea broke nearly over her, carrying two or three hundred souls with it as it receded into the ocean, of which number I was one. The life-preservers were mostly all tin, and were therefore not of much service as a slight dent from coming in contact with a solid substance would destroy them. But few cork preservers were on board." (*New-York Daily Tribune*, 21 September 1857).

Henry H. Childs – First Cabin Passenger. Henry Childs was a New York businessman who was rescued by the *Ellen*. He described his experiences following the sinking: "I think some four hundred or four hundred and fifty souls were launched upon the ocean at the mercy of the waves. The storm at this time had entirely subsided. We all kept near together and went as the waves took us. There was nothing or very little said except that each one cheered his fellow comrade on." He continued: "Courage was thus kept up for two or three hours, and I think for this space of time none had drowned, but three who could not swim became exhausted. The hope that boats would be sent to us from the two vessels we had spoken soon fled from us, and our trust was alone in Providence—'and what better trust could you or I ask for ?'" (*New York Journal of Commerce*, 19 September 1857).

Lt. John D. Dement – First Cabin Passenger. Mexican War hero Lt. John Dement, 31, was a member of the first United States military unit in the Oregon Territory. His wife and two-month-old son remained in Oregon City while he was traveled to Baltimore via New York (Klare 1992). At the time of the sinking he operated a store and a warehouse, having resigned from the army in 1853. Dement spent 13 hours in the water before being rescued by the *Ellen*, and was (along with passenger Robert T. Brown) one of the last two men saved.

After the sinking, Dement became very good friends with *Central America* Second Officer and fellow-survivor, James Frazer (Frazer moved to Oregon in 1858). By 1860 Dement and his brother William were involved in various enterprises including the establishment of the Oregon City Woolen Mfg. Co. and the building of the stern-wheel steamer *Rival*. Upon Dement's death in 1891, James Frazer wrote an obituary for the Portland *Oregonian* (25 January 1891). In 1991, a trunk originally belonging to John Dement was retrieved from the *Central America* shipwreck site. Several letters were found in the trunk which identified the owner (see Underwater Archaeology section later in this paper).

Ansel Ives and Adeline Mills Easton – First Cabin Passengers. Ansel and Addie Easton (Fig. 15) were married on 20 August 1857—the same day they left San Francisco on the *Sonora*. The trip was the first part of their planned honeymoon to Paris. Addie was 27 years old at the time of the *Central America* disaster and Ansel was 38. Addie was originally from North Salem, NY and Ansel was from New York state as well. He had come to California early in 1850 on the steamship *Tennessee* and was one of the founders of North Burlingame, CA. Ansel was a successful California businessman and Addie was the sister of Darius Ogden Mills of Sacramento and San Francisco, who was one of the wealthiest men in California. He had shipped $34,000 on the *Central America*, money that was lost with the rest of the steamer's gold shipment. In 1864, he and William C. Ralston founded the Bank of California in San Francisco; Mills eventually becoming its president.

Addie Easton's memories of their experiences on the *Central America* were recounted in a small book published 54 years later, *The Story of our Wedding Journey* (Lincoln 1911). In it, she describes her thoughts and feelings after the leak was discovered and the passengers began to bail the ship: "When too exhausted to work longer my dear husband would come and sit by me for a few minutes and with clasped hands we talked to each other of our dear, dear friends, of our brief happiness together and our hopes for the future . . . Life had never seemed so attractive or dear to either of us, yet the wonderful truth, which has so often been told of absolute calmness in the moment of death, became a reality to us."

Addie and her husband had with them on the steamer a number of packages of wine and food which had been given to them as wedding presents. She distributed the items among the men as they worked. *Frank Leslie's Illustrated Newspaper* (3 October 1857) described her actions in this way: "Among the ladies was Mrs. A. J. Easton [sic], who with her husband was on a bridal tour. She distinguished herself while on board the *Central America* by encouraging the passengers and crew who were engaged in bailing, supplied them with wine and food, and was altogether an angel of mercy."

Addie, like the other women, left the *Central America* for the *Marine*—believing that her husband would soon follow. He did not arrive at the *Marine* in any of the lifeboats, however. Describing her feelings, Addie later recounted: "I put my face down in my hands, too wretched to speak, reproaching myself that I had not stayed with him, regretting that I had not defied Captain [Herndon] and all when they ordered us to leave." When Addie was on the *Marine*, hoping against hope that Ansel would be in one of the lifeboats, a note from Ansel arrived for her: "My Dear Wife—If the Capt. of the *Marine* will send a boat forward for me you can give him what he will ask. I will watch for it & be on hand. Your Aff. Husband, A. I. E." Capt. Burt told Addie that he would if he could but that he had no lifeboats that could survive the trip. The note which Ansel sent Addie still exists and is in the collection of the San Mateo County Historical Association. Describing her feelings as she sat alone, watching the lights of the steamer from the *Marine*, Addie says: "Suddenly a rocket shot out obliquely, the lights disappeared beneath the waves, and all the world grew dark for me." (Lincoln 1911).

Addie described Ansel's experiences at the time of the sinking: "[Captain Herndon] turned to Mr. Easton and said, 'Give me your cigar, Easton, for this last rocket,' and as he was handing it to him the ship gave a great plunge . . . he . . . found himself among hundreds of human beings, each struggling for life. A large plank which had been the front of a berth floated by and this he grasped. On this he floated for eight hours. At first he could see the lights of the ship off in the distance. He thinks he must have been a little delirious for he had no fear of drowning and seemed to feel that he was reaching out to a far country . . . [Mr. Easton] did not see the ship, the *Ellen*, which finally rescued him, until she was very close. He was perfectly composed, took the rope thrown out to him, ascended, put on the dry clothing provided and went to work assisting in caring for those who were saved and calling out the names of every one he knew, hoping to get a response from the water." (Lincoln 1911).

One of the objects recovered from the SS *Central America* was a trunk full of well-preserved clothing and other personal items. Among the items in the trunk were lace-edged petticoats, robes, dressing gowns, embroidered shirts, coats, waistcoats, trousers, gloves, belts, gold studs, cuff links, and a pair of pistols. A photograph of an as-yet unidentified young man was also recovered from the trunk. Several shirts were marked with a name: "A. Ives Easton," indicating the trunk belonged to Ansel and Addie Easton (see Underwater Archaeology section).

Dr. Alvin A. and Lynthia Ellis and Family – First Cabin Passengers. The Ellis family had been living for several years in California and they were returning to their home in Waterford, OH, when the *Central America* disaster took place. In addition to her three children (Alvin, 2; Charles, 5; and Lillie, 1), Mrs. Ellis was caring for one child who was not her own—probably the child of a relative who had remained in California.

Mrs. Ellis gave no accounts to the newspapers, but passenger Jane Badger discussed her and her family: "As Mrs. Ellis, a very delicate lady in ill health, who had suffered greatly from sea-sickness during the whole voyage, was handed into the boat with her four little children, she asked that her husband, who was standing by, might be allowed to go with her to help take care of the children. This was refused, as it was said that no man would be allowed to go—but immediately afterwards Mr. Munson, Mr. Payne and one or two others were taken into the boat, with Mr. Ashby, while Mr. Ellis was left behind and lost." (*New-York Times*, 24 September 1857).

Dr. Obed Harvey – First Cabin Passenger. Dr. Harvey was a member of the El Dorado County Medical Society and operated El Dorado County Hospital in Placerville, CA. He treated many sick and injured passengers and crew members of the *Central America*, including the steamer's surgeon, Dr. Joseph T. Tennison, who was very ill for most of the voyage and was lost in the sinking. Dr. Harvey said, "The scene presented [when the ship sank] can scarcely have a human parallel—hundreds of souls launched into the boundless sea and left at the mercy of the waves . . . May kind Providence ever smile on the captain and crew of the Norwegian bark. They will ever be gratefully remembered by us. There was considerable sickness and suffering among the survivors, caused by extreme fatigue and injuries sustained at the time of the wreck. Finding a chest of medicine on board the bark, I was enabled to give such medical aid as was desired. They have all recovered or nearly so." *New York Herald*, 27 September 1857).

According to the *Southern Argus* (Norfolk, VA, 23 September 1857), Dr. Harvey "had in his possession a cane with a large and elaborately carved gold head set with gilt quartz. At the suggestion of a friend he cut the head off and threw the stick away. He brought it safely through, and exhibited it at Barnum's yesterday. It is valued at $50."

Dr. Harvey described his rescue and that of Second Officer Frazer in this way: "Having been in the water some five hours, and being entirely alone, a man came floating alongside of me with a chair; he seemed much exhausted, and placed his hand upon my floating substance for support. I hesitated at first in giving that aid desired, fearing that it would not support us, and that it would be the means of our both perishing. In conversation he told me that his name was Frazer (second mate) and that, if lost, would leave a destitute family in New York. I then knew him from acquaintance on ship-board, and told him to let his chair go, and share with me on my floating substance, and that we would sink or survive together. He was much exhausted, and becoming quite chilly and sleepy. Soon we discovered the rigging of a vessel at a distance, and taking renewed courage, although we had to make our way and swim against the current, we soon reached the Norwegian bark *Ellen*. The mate having sufficient strength in his hands, was drawn up by a rope without much difficulty . . . [We were] taken on board at 3 o'clock A. M. We were insensible for some time. We were among the first rescued." (*Mountain Democrat*, Placerville, CA, 14 November 1857).

Frederick and Ada Hawley – First Cabin Passengers. Frederick Hawley and his wife Ada, originally from Connecticut, were traveling with their two children, DeForest, 2 and Willis, 5 months. Ada told of a conversation with Frederick on the day before the sinking: "I asked my husband . . . if he was not tired of bailing; he replied, 'Yes, I am tired; but I can work forty-eight hours in the same way, if necessary. I am working for your life—for you and my children.'" (*Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857).

Ada and the children were rescued by the *Marine* but Frederick was lost. Ada was heartbroken with the tragic loss of her husband: "The last I saw of my husband was as the lifeboat pulled away from the ship. He stood on the side of the ship, and kissed his hand to me." She described her arrival at the brig: "Capt. Burt, with his mate, stood with open arms and a willing heart, to receive us. A rope was thrown, and in another moment the children were being passed out. Captain Burt took my little Willy, and the mate received DeForest, playfully saying as he passed him over the side, 'He is all gold.' My heart was lighter when I saw my children safely on board the brig. All the ladies were then passed out, and the boat immediately returned to the steamer." (*Hartford Courant*, Hartford, CT, 21 September 1857).

Frank A. Jones – First Cabin Passenger. Addie Easton commented on Frank Jones: ". . . handsome young fellow. Some said that he was a large landed proprietor of Kentucky, and some that he was the cleverest gambler in San Francisco." (Lincoln 1911). His black servant, Charley, was traveling with him and had steerage accommodations. Jones was rescued by the *Marine* but Charley was lost.

Jones described the efforts to keep the steamer afloat on Friday, 11 September 1857: "All hands, passengers and crew were ordered to go to work bailing, as none of the steam pumps would work. We rigged pulleys over the hatchways, and slung barrels which were filled, hoisted and emptied as fast as possible. The pulley ropes were manned by gangs of 50 men, as the donkey engines were useless. Bailing parties were also organized, who lined the stairways, and passed the water up in buckets. We were, by these means, enabled to keep the steamer afloat. All of us knew how desperate was our situation, and everyone worked with a will." (*New-York Daily Tribune*, 21 September 1857).

After the ladies and children had been taken from the *Central America*, Jones described the scene: ". . . all discipline was at an end, as the fate of the ship was rapidly and surely approaching. It was every man for himself. When the boats returned they would throw themselves overboard like sheep, filling them in an instant. Those who did not succeed in getting into the boats were hauled on board by means of ropes. In that trying hour gold was valueless. The miner threw his hard-earned 'pile' into the sea, lest its weight might drag him down. I saw many men thus relieve themselves of their treasure, and hundreds of thousands of dollars were thus thrown away." (*New-York Daily Tribune*, 21 September 1857).

Almira Mead Kittredge – First Cabin Passenger. Mrs. Kittredge, 39, originally from Lowell, MA, was the wife of Dr. F. M. Kittredge, of Santa Cruz, CA. She described the circumstances for the one child that was not saved: "There was a little Spanish boy [Ricardo Ollague] from Lima [Peru] 11 years old; he looked like a little boy of mine, and I became very much attached to him. I took the charge and care of him. He was to be put off the boat with me; they promised to do so but did not, and he was lost; he was the only child lost. He had an older brother [Adolfo, 27] on board who came to me and beseeched me to take the little boy with me. I promised to do so, but they would not put him on board." (*New York Herald*, 27 September 1857).

Almira Kittredge was widely quoted in the newspapers regarding conditions on the *Marine*: "When we got to the *Marine* the water was washing and dashing over her guards, and we were handed right into the water. Thirty women and twenty-six children were stowed into the little cabin by setting them down on the floor as closely as they could sit . . . I sat down right by the cabin door, through which the water was rushing in all night. I sat up all night up to my waist in water. The storm was very high, the sea broke over us, and the ship tossed to and fro like a feather in a gale. I shall never forget that night . . ." (*Daily Constitutionalist*, Augusta, GA, 1 October 1857).

Rufus A. and Harriet Lockwood and Family – First Cabin Passengers. Rufus Lockwood was an attorney, of the firm of Lockwood and Wallace in San Francisco. He was considered to be an exceptionally brilliant and determined man. In 1851, he became famous for his denunciations of the San Francisco Vigilance Committee and his many successes in court enabled him to develop a highly profitable law practice. He became an attorney for Col. John C. Fremont and was thought to be the greatest land title lawyer in California (Hastings 1955). At the time of the disaster, Rufus was about 46, his wife Harriet was 45, Rose Alice was 14, Rufus Albert was 12, and Harriet Maria was 9. Mrs. Lockwood and the children were rescued by the *Marine* but Rufus was lost.

Before the sinking of the *Central America*, according to various survivor accounts, Mr. Lockwood fell into despair, eventually refusing to work with the other men at bailing the ship. Harriet Lockwood said: "Respecting my husband, he worked at the pumps when first started until exhausted; but afterwards came into my state room and said—'It is no use to work; there is no command. If there was any command I would work.' I understand that after I left the steamer [my husband] worked to the last moment." (*New York Herald*, 27 September 1857).

An incident connected with one of the Lockwood children is described by Almira Kittredge (*New York Herald*, 27 September 1857) in her account: "The tables were set on Friday, and some of the passengers—mostly second cabin passengers—had taken dinner, when the captain called up all hands to help with the bailing. Two little girls, Miss [Harriet Maria] Lockwood and Miss [Augustine Rosalie] Pahud, got their dinner, nevertheless, and had a very merry time over it. The sea tossed the steamer about very violently, but the girls laughingly told us how they braced themselves to the table and ate away. When the dishes flew about smashing and crashing as they fell to the floor, the girls laughed merrily, thinking it was rare sport. They were decidedly jolly, little realizing the danger in which they stood."

William H. and Amanda Marvin – First Cabin Passengers. The Marvins were originally from Chicago, IL. William perished in the disaster but Amanda was rescued by the *Ellen*. William was a steamboat agent. Describing him, Almira Kittredge said: "Mr. Marvin worked until he could not speak, rested a moment, and again went to work." Amanda was energetic as attested by her fellow passengers. Almira Kittredge: "When the steamship *Central America* listed over to the starboard on Friday we got on the other side, and braced ourselves up by holding on to the tables . . . None of us went on the other side of the steamer except once in awhile a daring one, like Mrs. Marvin . . . Mrs. Marvin pulled up a little Irish boy and girl named Fallen [sic], second cabin passengers, from the second cabin, when it was half full of water. These children said they dared not go upstairs, because the men were passing water up the stairs. Poor creatures, they did not know what danger they were in." About this incident, Amanda said, "It was impossible to stand on deck when I pulled [the Fallon children] up, but by holding on to a table leg with all my strength I succeeded in getting them up." (*New York Herald*, 27 September 1857).

Judge Alonzo Castle Monson – First Cabin Passenger. Alonzo Castle Monson was 36 years old at the time of the *Central America* disaster. He was a brother-in-law of Robert H. Morris, former Supreme Court Judge and was a native of New York. He graduated from Yale in 1840 and Columbia University Law School in 1844. He had migrated to California in 1849 and became a judge in 1852. In August 1857, he resigned his position as Presiding Judge of the Sixth Judicial District in California (Sacramento County) and also resigned as President of the Society of California Pioneers. He was returning to New York to live.

Judge Monson had apparently made the trip a number of times before and was a good friend of Captain Herndon's: "At about 8 o'clock Saturday morning Capt. Herndon came to my stateroom. I had been an old acquaintance of his, occupied a seat on his left at table . . . The captain told me then that there was no hope for us unless the storm abated soon or some vessel hove in sight. I presume I was the only person on board to whom he communicated that fact. The captain was perfectly calm, and intimated that it was but to keep up the courage of the passengers and crew until the last moment." (*New York Herald*, 27 September 1857).

He described the circumstances of his rescue by the *Marine*: "After all the ladies and children had been taken from the steamer, I asked Mr. Van Rensselaer, the first officer, if he would not allow Mr. Priest, of Jamaica, L. I., who was the oldest passenger on board, to be taken next. Mr. Van Rensselaer said yes. I had previously requested Mr. Priest to remain in the cabin where I could find him, and at once told him that he could take his place in one of the small boats. I brought him to the forward part of the steamer and found the boat there full. I then took him to the after part of the vessel, and he was lowered into a small boat. I gave Mr. Priest a message to my brother in New York, in case I should not be saved myself. Mr. Priest said, 'Never mind the message, come, Judge, yourself.' Mr. Rensselaer said, 'Certainly, Judge, it is your turn—all right, jump in.' I immediately was lowered to the boat. A moment previous I had not the slightest idea of leaving the steamer then. At that time I believed that all on board would be taken safely off the steamer and placed on the brig." (*New York Herald*, 27 September 1857).

Theodore Payne – First Cabin Passenger. Theodore Payne, 40, was a San Francisco auctioneer. He was originally from New York, where his wife and sons were waiting for him.

He was apparently an acquaintance of Captain Herndon's, as he was entrusted by the Captain with a very special duty: "I went from the steamer in a boat to the brig *Marine*, immediately before she sunk. I am indebted to Captain Herndon for my life, as I was anxious to remain, and I only went off at his earnest request. I was in frequent consultation with him before I went, and he asked me what I thought of affairs. I said, 'Thank God, the women and children are all off, and we are strong.' He replied, 'Yes, thank God,' and he added, 'You take the next boat.' This I did, but before I went he requested me to go into his office and get his gold watch and chain, and if saved, to carry them to his wife. Said he, 'Tell her to—' but his utterance was choked by deep emotion, and he said no more on the subject, but changed it by saying he wished me to see the president of the steamship company, Marshall O. Roberts, and the agents, and communicate with them in relation to the disaster. After saying this much, he walked away a few steps and sat down on the bench, with his head to his hands, apparently overcome. He remained in that position for a few moments, and then arose and resumed giving orders, as the boat from the brig *Marine* returned." (*New York Herald*, 22 September 1857).

Theodore Payne reinforced Chief Engineer George Ashby's contention that the Chief Engineer was following Capt. Herndon's orders: "As Ashby left the steamer in the life-boat, Captain Herndon, through his speaking-trumpet, reiterated his order to have the captain of the brig lie by the steamer all night, as close as he could, and, if possible, get the brig's boat crew. This he did, as soon as he got on board." (*San Francisco Daily Evening Bulletin*, 4 November 1857). Support for George Ashby came from another source which also revealed the high esteem in which Theodore Payne was held, the Panama City Correspondent for the *New-York Times*: "Ashby may have been lax in the details of the duties properly belonging to his department on the steamer. That I know nothing about. But that he is a coward, or acted in a cowardly manner when danger surrounded him, no one on this Isthmus who knows him believes. Besides, Theodore Payne's testimony is conclusive, to my mind, in his favor. I know Mr. Payne—have known him for eight years—and no man's character or veracity stands better on this coast than his. If Captain Herndon is saved, and I pray God that he is, he will bear ample testimony to Mr. Ashby's good conduct after the disaster, and relieve him from the odium that is now sought to be attached to his name." (*New-York Times*, 17 October 1857).

Cdr. Herndon also asked him to communicate with the President of the United States Mail Steamship Company concerning the disaster. Upon reaching Norfolk, Payne dispatched two messages (consisting of about 150 words) to Marshall O. Roberts, President of the United States Mail Steamship Company, relating the details of the disaster. On 22 September, Payne called on Mrs. Herndon in New York and delivered to her the gold watch entrusted to him by her husband (Klare 1992).

Ann Small and Child – First Cabin Passengers. Mrs. Small was the widow of a sea captain who had died in Panama on 26 August 1857. She was traveling with her 2-year-old daughter, Anna. The American Consul of Panama had placed them in the special care of Captain Herndon. Her husband's ship was the *Augustine Herald* which had left New York in December of 1856. She was on her way home to Newburyport, MA.

As a sea captain's wife, she understood the way a captain felt about his ship: "Capt. Herndon remained self-possessed, calm and firm throughout. I shall ever think of him with gratitude. I am not surprised to hear that he is among the lost, because I knew by his appearance when I parted from him that he would be the last man to leave the ship. I understood from the steward that he had talked with the Captain during the night, and he said he knew what his mind was: he would not leave the vessel." (*New-York Times*, 21 September 1857). Despite her obvious misfortune, Ann Small spoke with optimism: "We have reason to be grateful, for we all feel that although we have lost a great deal, God has been very kind to us." (*New-York Daily Tribune*, 21 September 1857).

Joseph M. Bassford – Second Cabin Passenger. Joseph Bassford was a shipwright with a wife and family in Benicia, CA. Bassford leaped from the steamer into one of the lifeboats carrying the women and children to the *Marine*. Chief Engineer Ashby was among the boat's crew and had drawn a knife as a warning to those on the steamer that they must not jump and risk swamping the lifeboat. In his account, Bassford described the incident, saying, "I had a knife too at my command and was not to be awed by any such threat." Upon his arrival on shore, he was quick to attach blame for the disaster to Ashby, saying, "I am satisfied from what I afterwards learned, that had Ashby immediately went to work in endeavoring to remedy the difficulty with the engines, he might have got them to work again, and saved the vessel." His criticism extended to Captain Herndon as well, claiming that he was not equal to the present trying emergency.

However, he spoke highly of the courageous behavior displayed by the passengers, particularly the women: "At this crisis some of the ladies behaved most generously and nobly—several of them volunteering to take their places at the buckets; but the men, tired as they were, had too much gallantry to allow this. The offer of the ladies, however, to assume a portion of the trying toil, gave renewed encouragement to the men." (*New York Herald*, 21 September 1857).

Lawrence Fallon and Children – Second Cabin Passengers. Lawrence Fallon, originally of Sharon, CT, was traveling with his 17-year old daughter, Winifred, and her younger brother, James. They had been living in San Jose, CA, before the voyage. Winifred and James were rescued by the *Marine*, but their father was lost.

Winifred described her frightful ordeal: "The first time I felt of the storm was on Wednesday; I got up and had to go to bed again, where I staid until Saturday. On Saturday the state-room that Mrs. Redding and I occupied had three feet of water in it. I lay there those four days without tasting a morsel of food, and Friday night a man came down and picked up every blanket and counterpane and mattress to stop the leaks. At about 10 o'clock on Saturday a gentleman came down and took us into the saloon; my father was with us; he handed me his money and told me to keep it—perhaps I might be saved and he not. This was before we came in sight of the brig. After we got sight of the vessel I handed it back to him; I told him that it was too heavy. Then they called us up to the lifeboat; I came on the second boat to the brig; I think the terror will never leave my heart; I felt as though I had almost as lief go down with the ship as to get off; the ship was on her side for two days before we left her . . ." (*New-York Daily Tribune*, 21 September 1857).

Jane Harris and Child – Second Cabin Passengers. Jane Harris was traveling with her infant child. Her husband had remained in San Francisco. She explained the men's efforts to keep the women unaware of the severity of the situation at hand: "The accident was not dreamed of in the cabin until hours after it was known on deck. We knew that the engine stopped, and we sent to inquire what the matter was, but a man answered that 'The wheels were tired and wanted to stop a while.' He gave this answer, I suppose, partly because it was a little boy that we sent upstairs to ask him, and partly because he wanted to prevent exciting the alarm." (*New-York Daily Tribune*, 21 September 1857). Later, Captain Herndon came down into the cabin and he: "did not try to disguise the danger, but he made us all look more cheerfully at it than some other man might have done." (*Crawfordsville Review*, Crawfordsville, IN, 3 October 1857).

Jane Harris described her trip to the *Marine*: "As soon as we approached the brig near enough to get on board, I watched for a chance to spring at the rigging, and to get hold of a rope. I had a life preserver on, which somewhat encumbered me, and almost prevented my escape. I caught the rigging with my hands, but my life-preserver under my arms was so large that I could not get between the ropes. I hung there for a few moments over the side of the ship, in almost equal peril as when I dangled at the end of a rope over the side of the steamer. I was every moment expecting to fall, when the captain caught hold of me, and pulled me in by cutting off my life-preserver." (*New-York Daily Tribune*, 21 September 1857).

John O. Stevens – Second Cabin Passenger. Stevens was a trader, miner, and orchardman who had been in California for eight years. He was born in New Jersey and was 32 years old. He joined the Audubon Company in New York and they trekked across Mexico to San Diego in 1849, and then by sea to San Francisco, and overland to Stockton. The expedition was led by John Woodhouse Audubon, son of the famous naturalist (Audubon and Hodder 1906). Audubon made hundreds of sketches of the birds, mammals, and frontier life. When he left California in 1850, about 200 sketches were left behind with attorney Robert Simon in San Francisco. Complying with Audubon's wishes, John Stevens was given the portfolio of sketches to deliver to New York and he booked passage on the *Sonora*. The drawings never reached their destination for both Stevens and the portfolio were lost (Van Nostrand 1942). Fortunately, 34 of Audubon's original pencil and water color sketches sent on an earlier overland journey to New York and therefore, were not on board (Fig. 28).

FIGURE 28. Two of the 34 surviving John Woodhouse Audubon sketches from his 1849 western expedition. The one titled *Night Watch* (top) is inscribed: "John Stevens, July 11, 1849, Conception Western Mexico–Moonlight, gay blanket, red shirt, on guard–2 o'clock am." In *The Forty Niner* (bottom), the man on horseback also appears to be John Stevens. Reproduction courtesy of Southwestern Museum, Los Angeles, CA (Accession nos. 22.G.978s and CT.493); all surviving sketches are now in the collections of the Braun Research Library, Southwestern Museum.

Jacob M. and Randolph W. Casey – Steerage Passengers. The Casey brothers, Jacob and Randolph, were 25-year-old identical twins. They were miners who originally came from Sebastian County, AR. Both were rescued by the *Ellen*. One of the Casey brothers (unspecified) was interviewed by the *New York Herald* (21 September 1857) about the events immediately after the sinking: "On rising again to the surface I heard the people who were in the sea crying, 'Don't hold me,' 'you will drown me,' &c. Seeing such confusion I guessed that it would be better for me to get as far from the rest as possible, so I paddled out my plank the best way I could until I heard the cries, moans, &c., at some distance, and then I knew that I was away from most of them, but it was so dark that I could see nothing, and gradually the noise of voices became more indistinct and less smothered moaning was heard. In fact, I may almost say that I was alone, without either seeing or hearing anything but the storm and rough sea. . ."

William Chase – Steerage Passenger. William Chase was a miner originally from Washtenaw County, MI, who had been in California since 1852. He described the scene on board the *Central America* shortly before the sinking: "After it became apparent that the ship must sooner or later surrender to the angry elements, the scene among the passengers on deck and throughout the vessel was one of the most indescribable confusion and alarm. The prayers of the pious and penitent, the curses of the maddened, and the groans and shrieks of the affrightened, were all coming together, added to which were numerous angry contests between man and man, in many instances amounting to outright fights for the possession of articles on which to keep themselves afloat in the water." (*Daily Evening Bulletin*, San Francisco, CA, 24 October 1857).

"A great many of the passengers were miners, having considerable sums of gold about them, the product of years of toil; but the love of gold was forgotten in the anxiety and terror of the moment and many a man unbuckled his gold-stuffed belt and flung his hard earned treasure upon the deck, some hoping to lighten their weight, and thus more easily keep themselves afloat, while others threw it away in despair, thinking there was no use for it in the watery grave they were going to . . . I might have picked up thousands of dollars which had been thrown away and lay strewn about the decks . . ." (*Detroit Free Press*, 23 September 1857).

Chase said that, ". . . the effect of the sinking of the ship as like that produced by inserting a red-hot bar of iron into a tub of water—a moment's hissing and seething, and she was enveloped in the angry flood." (*Detroit Free Press*, 23 September 1857).

A fellow passenger, Enrique Ayulo of Peru, described the same scene: "At the time of the going down of the steamer there arose a hoarse yell, as if coming from the bottom of the ocean, and in a moment all was over." (*New-York Times*, 21 September 1857).

Chase observed that: "Mr. S. Caldwell [Steerage passenger], of New York, had twenty pounds of gold dust in a belt about his waist. He kept himself afloat upon a door which he secured at the time the ship sank . . ." (*Detroit Free Press*, 23 September 1857). Stephen Caldwell later said of the final minutes on the *Central America* he saw: "fifteen or sixteen men who had locked themselves up in their staterooms, saying they would rather die there than go down struggling, with death in the water. Five or six were sick in their berths." (Klare 1992). Caldwell, as well as Chase and Ayulo, was rescued by the *Ellen*.

George W. Dawson – Steerage Passenger. George Dawson was a 35-year-old free black living in the pre-Civil War United States. He was described by the *New York Herald* (6 October 1857) as: ". . . tall, well-built and muscular . . . must have had an iron constitution to have endured the more than human sufferings his tale of horror recounts." Dawson, who was unmarried, had been working as a porter at the St. Nicholas Hotel in Oroville, CA. The hotel was one of the stage-coach depots for the California Stage Company, owned by First Cabin passenger James Birch, and Dawson probably met Birch at the hotel. Before leaving California, James Birch had received a silver cup from a friend (John Andrews) as a gift for Birch's young son Frank. The cup was inscribed, "From John to Frank." As the steamer was about to sink, Birch became despondent over his own chances for survival. He called on his acquaintance George Dawson and entrusted the cup to him.

Describing the situation shortly before 8:00 PM, George Dawson stated: "that when the steamer had sunk so far as to burst the second-cabin floor from its fastenings, and force it up to the first cabin, he became satisfied that to work longer was labor thrown away. He went on the forward deck and assisted some men in putting a raft over the side of the vessel, which they had made by cutting out a section of the forward deck and lashing it with ropes." (*New-York Daily Tribune*, 6 October 1857). First Cabin passenger Charles A. Vose also observed: "There were 600 or 700 tin life preservers on board, and it is probable that every person succeeded in getting one or more of them . . . Some had rigged rafts out of state room doors and other portions of wood work with ropes to hang on by. These rafts were generally large enough to carry four or five persons." (*New York Journal of Commerce*, 21 September 1857).

After the steamer went down, Dawson floated for about seven hours clinging to a plank, and eventually found himself near a raft, made from the ship's hurricane deck, on which several other persons floated (including fireman Alexander Grant, with whom, in a strange coincidence, Dawson had been shipwrecked two years earlier on the steamship *Crescent City*). ". . . he was not allowed to come on board, [so] he took hold of a rope with one arm and supported himself in the water by his plank. He remained in this position many hours, until several occupants of the raft died; when he finally found himself not only on board, but useful in cheering up his mates." (*Frank Leslie's Illustrated Newspaper*, New York, 17 October 1857).

On Thursday, five days after the sinking, Dawson and Grant (now the only survivors on the raft) caught sight of one of the lifeboats of the *Central America* and on reaching it found it occupied by Second Assistant Engineer John Tice. They joined him on this somewhat safer vessel and four days thereafter were sighted and rescued, by the British brig *Mary*.

After returning to New York, George Dawson located James Birch's widow Julia Birch and presented the silver cup to her, faithfully honoring the pledge he had made to her husband before the sinking of the SS *Central America*. This cup is now in the possession of the University of California, Berkeley, and on display in the foyer of the Hearst Memorial Mining Building.

Oliver Perry Manlove – Steerage Passenger. Oliver Manlove traveled overland from Wisconsin to California at the age of 23 in 1854. He worked on mining claims in California for several years and sent money home. During his years in the gold fields he wrote a book of poems which was lost with the sinking of the *Central America*. He was rescued by the *Ellen*.

Oliver Manlove described the moment of the sinking: "Now the vessel gave three lurches, some of the passengers jumping off at each lurch. Those who jumped off at the first and second lurches swam off to some distance. But the great mass remained on deck until the vessel went down, which was a minute or two afterwards." (*Red Ring Republican*, Red Wing, MN, 25 September 1857). Fellow steerage passenger Barney M. Lee was one of those who was washed off the deck: ". . . the vessel was so low in the water that almost every wave broke over her and cleared her decks of almost everything; and I, with several other passengers, was swept off also at this time by one monstrous wave . . ." (*New York Herald*, 21 September 21). Manlove continued: "The Captain had cut away the upper works of the vessel, so that when the hull sank they would float off, but they were dragged down and came up in fragments. Many persons were killed, stunned or drowned, by being struck with pieces of the wreck; whilst the pieces were to others the ultimate means of safety." (*Indianapolis Daily Journal*, 22 September 1857). After the sinking of the *Central America*, he returned home, to Grant County, WI. In 1863 he joined the Union Army and fought with the 37th Wisconsin Regiment in Virginia. He was captured by the Confederates and held as a prisoner of war. After the Civil War, he settled near Hubbard, MN and became an accomplished poet and writer. He wrote his autobiography, which includes descriptions of his trips to and from California—including a description of the sinking of the *Central America* (Manlove 1915).

Henry T. O'Connor – Steerage Passenger. Henry O'Connor, 17, was traveling with his mother, Eleanor, and a young boy (Louis Bonneau) sent in her charge, both of whom were rescued by the *Marine*. Henry was rescued by the *Ellen*. They were bound for their home in Albany, NY. Henry worked as a printer at O'Meara & Painter. They had come to San Francisco in 1854. Eleanor established a dressmaking shop and earned about $3 per day. In the three years in California, she managed to save $2,000 for Henry's education (*Albany Evening Journal*, 23 September 1857). Henry O'Connor studied law, and in 1865 he was an attorney in Albany and boarded with his mother (Klare 1992).

Henry described the sinking: "I remained upon the steamer till she went down and I went down with her. Just before she went down the second mate got the captain a life preserver . . . Captain Herndon remained on the wheelhouse and went down with the ship. She sank at half past eight by the steamer's clock. I put on a life preserver when they were taking the women on board the brig, and worked at the buckets as much as I was able to from the time we were called until the vessel sunk. I was beside the wheelhouse, sitting down and holding on to the scuttle when she went down."

"When the vessel sunk I went down with her, and a good way down, but I don't know how far, it must have been fifteen or twenty feet. I was under a good while, and could hardly keep my breath while under. When I came up there were hundreds of human heads floating all around me . . . When I came up out of the water after the vessel sank, the men about me were all screeching for assistance. There were no lights near. I could see some of their struggling forms. There was no moon, but it was clear overhead; the stars shone bright, so that it was not very dark. I had cramps in my limbs a great deal and at one time cramps in both legs at once."

"I happened to float near the bark *Ellen*, and the sailors threw me a rope, and I grabbed it, and tried to hold on to it, but had not strength enough to hold on to be drawn up. As I got hold of the rope, two men got hold at the same time; I asked them to let go, and they did so. I then got the rope alone and twisted it around my waist, and held it to until they hauled me up. I do not know whether the men who let go of the rope when I requested them to were saved or not; I do not know who they were; when I got aboard of the bark *Ellen* they helped me down in the cabin, as I was not able to walk." (*New York Herald*, 21 September 1857).

Samuel and Mary Swan and Child – Steerage Passengers. The Swans, from Rough and Ready, Nevada County, CA, were traveling with their infant daughter not yet two years old. Mary and the child were rescued by the *Marine*; Samuel was lost. Mary described her departure from the steamer: "When it was my turn to leave the ship . . . my husband left his place at the pumps to assist me into the lifeboat. I needed assistance from some one, because early in the morning I was thrown suddenly out of my berth by a lurch of the ship, and was considerably lamed by the bruise. The rope was put around my waist, as around all the other ladies, and I was lowered without accident. When the boat reached the brig, I did not leap for the rigging, but held out my hand to the men on board, and was caught hold of. But they slipped their hold, and I fell into the water. I was got hold of again and partially lifted out, but fell into the sea three times before I was finally rescued. My falling so often, together with my injury of the morning, rendered me unable to stir in my bed for nearly three days. My babe was put into the boat before I was, and was safely got out."

"The last I saw of my poor husband was when he helped me into the boat . . . About an hour before I left, he took me aside and bade me 'Good bye.' He said 'I don't know that I shall ever see you again.' He was very glad to think that I could be taken off. He wanted me to go, and said that he did not care about himself, if it were possible that I could be saved, and the little child. He told me that he would try to save himself if an honorable opportunity should present itself after all the women were taken off. He had been sick for three or four days before the disaster, but not withstanding this, he persisted in keeping his place at the pumps."

"On Saturday night I knew that the steamer had gone down, before it was reported to us. I looked out through a window about 8 o'clock, and saw her light burning, and looking out again shortly afterward, I saw no light. I then felt sick at heart, for I knew that my husband must have perished in the meantime." (*New-York Times*, 21 September 1857). When she finally arrived in New York, she was asked if she knew anyone in the city. She replied: "No, I have no friends in New-York, nor in all the world, now that my husband is lost."

Capt. Hiram Burt – Captain, brig *Marine*. Captain Burt came to the aid of the sinking *Central America* and rescued 100 people; all the women and all but one of the children were saved. The *Philadelphia Daily Evening Bulletin* (14 October 1857) reported: "The conduct of Captain Burt was noble in the extreme . . . like a noble-hearted sailor, and a true and gallant man, he bore down with his half-wrecked brig to the aid of those whose dangers and necessities were greater than his own."

The rescued passengers praised Captain Burt, as the following quotes illustrate: "We were very kindly received, and very generously treated, on board the brig. The captain, who opened his whole heart to us, gave us every conceivable thing which could conduce to our comfort, and which was in his power to give." (Angeline Bowley, *Chicago Tribune*, 23 September 1857). "In common with the other passengers rescued by the brig . . . I would speak in the highest terms of the kindness and unremitting attentions of Capt. Burt and the crew." (Theodore Payne, *New York Herald*, 22 September 1857).

Frank Leslie's Illustrated Newspaper (17 October 1857) printed: ". . . although appearing much younger, [Captain Burt] claims to be forty-five years of age. He had a New England boy's education up to fifteen, when he went to sea." He was a resident of Taunton, MA. Captain Burt said of the passengers he rescued: "I can truly state that I could have rescued none more worthy and none who could have conducted themselves in a more noble manner whilst on board my vessel." (*New York Journal of Commerce*, 23 September 1857). He also indicated that he had only one regret and that was: ". . . that he could not have saved every life on board the ill-fated ship." Through the efforts of Addie Easton, Capt. Burt was awarded $600 and a gold watch (Klare 1992).

Capt. Samuel D. Stone – Captain, schooner *El Dorado*. The *El Dorado* sighted the sinking *Central America* at about 4:00 PM on Saturday, 12 September and came very close to the steamer. According to Capt. Stone, Capt. Herndon spoke to him, saying, "Lay by me til morning," and he promised to do so. The *El Dorado*'s first mate G. Sherlock said: "When Captain Herndon hailed the schooner his voice was as steady as if he had the best vessel in the world under him, in a smooth sea." (*Frank Leslie's Illustrated Newspaper*, 17 October 1857). Herndon was able to verbally pass to the first mate what is believed to be the position of the *Central America* at 7:00 AM from a lunar celestial fix. Capt. Stone reported his position at 6:30 PM when he spoke to the sinking steamer as latitude 31° 25' N, longitude 77° 10' W, wind northwest (*New-York Times*, 28 September 1857). During the next few hours the *El Dorado* drifted away and about 7:30 PM, seeing that the lights of the steamer had disappeared and fearing that it had sunk, he attempted to locate and rescue survivors—but could find no one.

The incident was widely discussed in the newspapers and Captain Stone suffered a great deal of criticism. In his statement (*Daily Constitutionalist*, Augusta, GA, 1 October 1857), he says that: "I had no idea that the other vessels in sight had on board persons saved from the wreck." In a letter to the *New-York Times* (28 September 1857), passengers Thomas Badger, Henry Childs, Ansel Easton, and Obed Harvey said: ". . . we cannot refrain from stating truth, as it appears to us, in regard to the statement of Captain Stone of the Schooner *El Dorado* . . . Captain Stone acknowledges he saw the rockets and the ship when she sunk. Had he shook out his reefs and made full sail, for which he could easily do, there being little wind, he could probably have rescued many of the lost from their watery grave . . . He also says that he stood directly over the spot where the steamer sunk; had he done so, many hopes would have been realized, as he was anxiously expected." Whatever the circumstances, Captain

Stone did not rescue anyone from the *Central America.*

Capt. Anders Johnsen – Captain, Norwegian bark *Ellen*. Captain Johnsen rescued 50 *Central America* passengers and crew members who had been floating on the sea for several hours after the steamer sank. The circumstances of his arrival at the scene were most peculiar, as he related in the *New York Herald* (22 September 1857): "Just before six o'clock on the afternoon of September 12, I was standing on the quarter deck . . . Suddenly a bird flew over around me, just grazing my right shoulder. Afterwards it flew around the vessel then it again commenced to fly around my head. It soon flew at my face, when I caught it and made it a prisoner . . . When the bird flew to the ship the bark was going a little north of northeast. I regarded the appearance of the bird as an omen, and an indication to me that I must change my course. I accordingly headed to the eastward direct. I should not have deviated from my course had not the bird visited the ship, and had it not been for this change of course I would not have fallen in with such passengers of the *Central America.*" (Fig. 29).

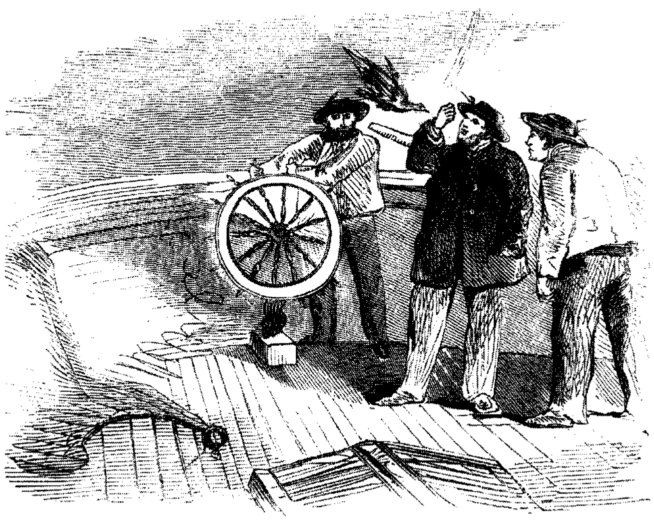


FIGURE 29. Capt. Anders Johnsen of the Norwegian bark *Ellen* being "guided" to the sinking of the *Central America* by a frigatebird (*Fregata magnificens*). Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

John James Audubon's son Victor, who worked with his father on the monumental publication of *The Birds of America*, identified the bird which caused Captain Johnsen to change his course as undoubtedly: "a frigate pelican [called a man-o'-war-bird by sailors]" (*New York Herald*, 22 September 1857). This species is now known as a Magnificent Frigatebird (*Fregata magnificens* Mathews) (Audubon 1937, Peterson 1980).

The Philadelphia *Daily Evening Bulletin* (22 September 1857) reported: "Capt. Johnsen is a small, very plain and unassuming man, with a countenance beaming with good nature and benevolence. His age is about thirty-five. He speaks English very well, but slow."

Survivor Billy Birch attested: "The conduct of Capt. Johnson [sic] merits the highest praise. His action in coming to the aid of the sufferers was prompt, and the search was continued as long as a hope remained that another life could be saved. His kindness to the saved was afterwards unceasing." (*Charleston Courier*, 23 September 1857).

Passenger Capt. Thomas Badger said of Capt. Johnsen: "He launched his boat, and threw out ropes and buoys, and done everything that good seamanship and a human heart could dictate to save as many as possible. I was the fourth one rescued, and witnessed the noble exertions of himself and crew throughout the night. He continued his search among the drift wood, tacking backward and forward, up to 12 o'clock on Sunday, but did not find anyone after 9 o'clock in the morning, and consequently relinquished the search at noon." (*New York Journal of Commerce*, 21 September 1857).

As an award for saving the *Central America* passengers, a gold pocket chronometer and chain, valued at $350, was sent to Captain Johnsen from President James Buchanan. He was also offered $2,500 by the United States Mail Steamship Company as reimbursement for damages to the *Ellen* but the repairs were done at U.S. Government expense (Klare 1992).

Capt. John N. McGowan – Captain, steamship *Empire City*. John McGowan was captain of the *George Law* on her maiden voyage in October 1853 and for the following five trips. At the time of the sinking he was in command of the *Empire City*, another United States Mail Steamship Company steamer that was operating along the Atlantic Coast. He was born in Philadelphia, PA, in 1805. He had served in the Squadron of Commodore Matthew Perry during the Mexican War, as had Herndon. The *Empire City* and the *Central America* were in Havana Harbor at the same time on 8 September 1857 and McGowan had visited with Herndon just before the fateful voyage (Klare 1992).

The *Empire City* weathered the same storm that sank the *Central America* and anchored at the quarantine zone off Norfolk, VA, on 15 September. He dispatched a message to the steamship company office in New York; "Quarantined in port at Norfolk. Arrived at this port this morning at 7 o'clock, encountering one of the most severe gales of wind I have ever witnessed, commencing Thursday at 12 o'clock; the wind varying during the time NE to SW, around by west, and blowing furiously from each point." (*New-York Daily Tribune*, 18 September 1857). He also detailed the considerable damage to his ship and that he would sail for New York on 17 September. On that date McGowan received a wire from Marshall Roberts, president of the steamship company, to send his passengers to New York by railroad and to proceed to sea at once to search for the *Central America* now overdue in New York.

At dusk on 17 September, the *Ellen* entered Norfolk Harbor, where at daylight on 18 September, Badger, Easton, Birch, and others engaged a pilot boat to take them to Norfolk. En route, they encountered the *Empire City* heading out to sea and informed McGowan of the disaster. McGowan proceeded to the *Ellen* and took on the majority of the survivors, offering them passage to New York. Off New Cape Henry, McGowan found the brig *Marine* in tow of the propeller *City of Norfolk.* Most of the survivors were taken on board the *Empire City* where the Seeger and O'Connor families were reunited. Addie Easton and Jane Badger were told that their husbands were safe and in Norfolk.

Captain McGowan had been informed by the survivors on the *Ellen*, including Joseph Bassford, of George Ashby's alleged cowardliness. Bassford described McGowan's reaction: "Upon arriving within 25 miles of Norfolk, the *Empire City* met us and took on board . . . the passengers from the *Central America*. Mr. Ashby, the chief engineer of the *Central America*, was going on board with the others, but Captain McGowan told him not to come on his steamer. Mr. Ashby wished to know the reason for refusing him a place on board. Captain McGowan gave him plainly to understand, and so told him in substance, that he acted most cowardly in deserting his steamer, and assured him that if he attempted to set foot on his steamer he would blow his damned brains to hell. Ashby attempted an explanation, but Captain McGowan would listen to no explanation, but asserted that he based his action upon reliable information touching Ashby's selfish cowardice and would have nothing to say to him." (*New York Herald*, 21 September 1857).

Commodore Matthew Calbraith Perry–Chairman, New-York Board of Underwriters Investigating Committee. When the Mexican War started in 1847, Commodore Matthew Perry, an early proponent of the steam navy, was in command of a squadron in the Gulf of Mexico. He requested an: "intelligent officer who could speak the Spanish language." Lt. Herndon was assigned to the squadron and placed in command of the steamer *Iris* where he: "successfully carried out dangerous assignments between the American squadron and the troops on shore" as well as American refugees who were starving on the beach at Campeche, Yucatan (Klare 1992). Lt. John McGowan, the first captain of the *George Law*, also served with Herndon in Commodore Perry's squadron.

In 1854 Commodore Perry led an expedition to Japan that successfully negotiated a treaty that opened Japan to American commerce. He sent Captain H. A. Adams, USN to Washington with dispatches that included the American treaty which had been signed on 31 March 1854 at Yokohama. As part of his return trip, Capt. Adams was a passenger on the ninth voyage of the *George Law* which sailed from Aspinwall on 1 July 1854 (Ridgely-Nevitt 1944).

In 1857 Commodore Matthew Perry was appointed by the New-York Board of Underwriters as chairman of an investigating Committee that was established to investigate the causes of the loss of the steamer *Central America*. The Committee issued two reports (Perry et al. 1857, 1858). In reporting on the findings of the Committee, the *New-York Times* (1 December 1857) stated: "It cannot and should not be concealed that the testimony before the Committee goes to show that the *Central America* was not sound and equipped as she ought to have been, that her crew was not sufficiently numerous, that she was without a carpenter or suitable carpenter's tools, and what seems to the Committee a most serious defect, being common, it is feared, in many of our passenger steamers, there was a want of proper organization in regard to the relative authority and duties of the officers and crew of the vessel; each department appearing to be independent of the others, instead of being strictly subordinate and responsible to the Captain . . . and this independence of action was the more observable in the department of the engineer." The Committee stated that it was: "well aware that all of their recommendations for reform or change would be strongly opposed. Nevertheless, they considered the proposed improvements to be plausible, and necessary to insure greater safety in ocean navigation." (Klare 1992). These recommendations included the following:

1. Large vessels should have at least four watertight cross bulkheads, with watertight doors to allow the passage of a coal car and a railway constructed for that purpose.
2. Pipes should be sufficiently strong and their valves placed in view of the engineers and firemen.
3. There must be positive access to the lower ends of the receiving pipes of the bilge and injection pumps.
4. All deck pumps and stationary pipes connected with the donkey pumps should be enclosed in pump wells large enough for a small man to clear the lower openings.
5. Provisions for adequate lifeboats, their manning and contents, including emergency gear.
6. Suitable spars should be carried for the construction of one or more rafts.
7. Appropriate use of qualified passengers in an emergency.
8. Those who superintend management of the vessel and engines should be the last to desert their posts.

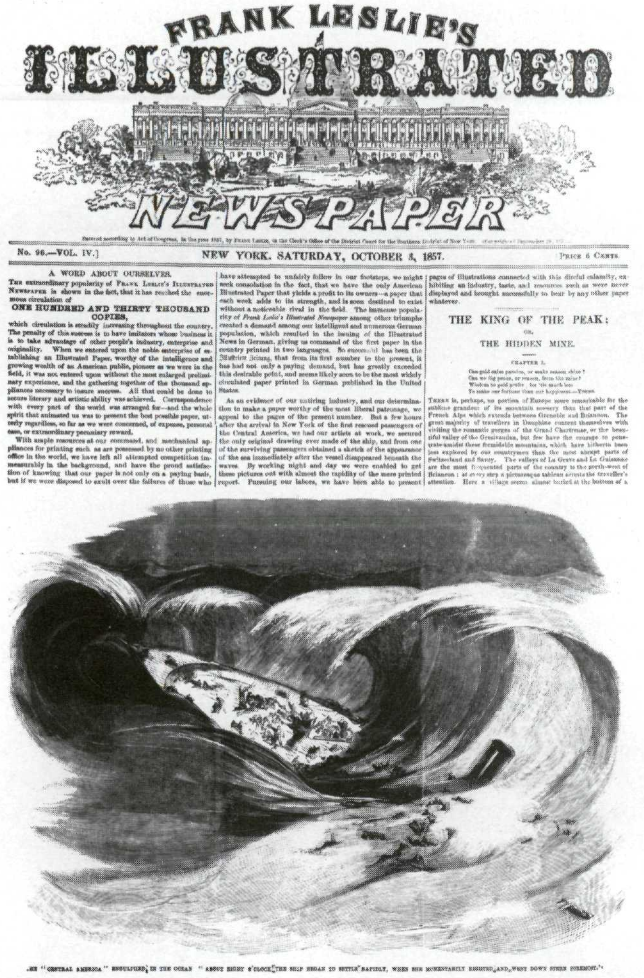
Shortly before the inspectors' recommendations were made public, the United States Mail Steamship Company announced that water-tight bulkheads and extra pumps for each compartment were being provided for all their steamers and that fire and engine rooms were all to be enclosed. (*New-York Times*, 2 October 1857).

Repercussions of the Sinking

Social Impacts. The sinking of the *Central America* was a major media event and newspapers interviewed the survivors at length in Norfolk, Savannah, and New York (Fig. 30). The national press continued to pursue the tragedy for months afterwards, calling for investigations and speculating on the causes of the sinking. Editorials demanded greater safety at sea and pressed for the construction of a transcontinental railroad. The sinking resulted in the loss of 425 lives, the nation's worst civil maritime disaster.

Delgado (1983, 1990) pointed out that the loss of the *Central America* had wide-reaching repercussions, particularly in America's determination to make ocean travel safer, but it also was a precursor of the end of the nation's most traveled steamship route. Within 12 years, the movement to build a transcontinental railway reached fruition, bolstered by the sinking of the *Central America* and other steamship disasters on the Panama Route. The completion of the railroad in 1869 brought an end to the heyday of the California steamers.

Most prominent among the names of the lost was the captain of the *Central America*, Cdr. Herndon. A grateful nation commended him for the orderly rescue of the women and children, his maintenance of discipline, and



FRANK LESLIE'S ILLUSTRATED NEWSPAPER

No. 96.—VOL. IV.] NEW YORK, SATURDAY, OCTOBER 3, 1857. PRICE 6 CENTS.

A WORD ABOUT OURSELVES.

The extraordinary popularity of Frank Leslie's Illustrated Newspaper is shown in the fact, that it has reached the enormous circulation of

ONE HUNDRED AND THIRTY THOUSAND COPIES,

which circulation is steadily increasing throughout the country. The penalty of this success is to have imitators whose business it is to take advantage of other people's industry, enterprise and originality. When we entered upon the noble enterprise of establishing an Illustrated Paper, worthy of the intelligence and growing wealth of an American public, pioneer as we were in the field, it was not entered upon without the most enlarged preliminary experience, and the gathering together of the thousand appliances necessary to insure success. All that could be done to secure literary and artistic ability was achieved. Correspondence with every part of the world was arranged for—and the whole spirit that animated us was to present the best possible paper, utterly regardless, so far as we were concerned, of expense, personal ease, or extraordinary pecuniary reward.

With ample resources at our command, and mechanical appliances for printing such as are possessed by no other printing office in the world, we have left all attempted competition immeasurably in the background, and have the proud satisfaction of knowing that our paper is not only on a paying basis, but if we were disposed to exult over the failures of those who have attempted to unfairly follow in our footsteps, we might seek consolation in the fact, that we have the only American Illustrated Paper that yields a profit to its owners—a paper that each week adds to its strength, and is soon destined to exist without a noticeable rival in the field. The immense popularity of *Frank Leslie's Illustrated Newspaper* among other triumphs created a demand among our intelligent and numerous German population, which resulted in the issuing of the Illustrated News in German, giving us command of the first paper in the country printed in two languages. So successful has been the Illustrirte Zeitung, that from its first number to the present, it has had not only a paying demand, but has greatly exceeded this desirable point, and seems likely soon to be the most widely circulated paper printed in German published in the United States.

As an evidence of our untiring industry, and our determination to make a paper worthy of the most liberal patronage, we appeal to the pages of the present number. But a few hours after the arrival in New York of the first rescued passengers of the Central America, we had our artists at work, we secured the only original drawing ever made of the ship, and from one of the surviving passengers obtained a sketch of the appearance of the sea immediately after the vessel disappeared beneath the waves. By working night and day we were enabled to get these pictures out with almost the rapidity of the mere printed report. Pursuing our labors, we have been able to present pages of illustrations connected with this direful calamity, exhibiting an industry, taste, and resources such as were never displayed and brought successfully to bear by any other paper whatever.

THE KING OF THE PEAK;

OR,

THE HIDDEN MINE.

CHAPTER I.

There is, perhaps, no portion of Europe more remarkable for the sublime grandeur of its mountain scenery than that part of the French Alps which extends between Grenoble and Briancon. The great majority of travellers in Dauphine content themselves with visiting the romantic gorges of the Grand Chartreuse, or the beautiful valley of the Gresivaudan, but few have the courage to penetrate amidst these formidable mountains, which have hitherto been less explored by our countrymen than the most abrupt parts of Switzerland and Savoy. The valleys of La Grave and La Guisanne are the most frequented parts of the country to the north-west of Briancon; at every step a picturesque tableau arrests the traveller's attention. Here a village seems almost buried at the bottom of a

THE "CENTRAL AMERICA" ENGULFED IN THE OCEAN "ABOUT EIGHT O'CLOCK THE SHIP BEGAN TO SETTLE RAPIDLY, WHEN SHE MOMENTARILY RIGHTED AND WENT DOWN STERN FOREMOST."

FIGURE 30. Newspaper account of the SS *Central America* disaster shows the ship engulfed in the ocean. Word of the tragedy was rapidly spread throughout the eastern states by means the newly constructed telegraph system. Interviews of survivors were key elements in the newspaper reports. Reproduced from *Frank Leslie's Illustrated Newspaper*, New York, 3 October 1857.

his personal courage in remaining with his ship to the last. The town of Herndon, VA, was named in his honor, his widow received a posthumous medal from Virginia (Sebring 1993); and a monument to his deeds was erected at the U.S. Naval Academy in Annapolis, MD, in 1859 (Fig. 31). The plaque on the monument reads: "Commander William Lewis Herndon, 1813-1857, Naval Officer – Explorer – Merchant Captain. In command of the *Central America*, home-bound with California gold-seekers, Captain Herndon lost his life in a gallant effort to save ship and lives, during a cyclone off Hatteras, September 12, 1857. 'Forgetful of Self, in his death he added a new glory to the annals of the sea' – Maury." The quote at the end of the inscription was written by Lt. Matthew Fontaine Maury, Superintendent of the U.S. National Observatory and Cdr. Herndon's brother-in-law.

Economic Impacts. In 1857 the United States was in the midst of the greatest economic transformation in the nation's history (Van Vleck 1967). This transformation was in two forms: 1) a shift within the economic system from agriculture to industry and 2) agriculture itself was being changed from self-sustaining household production to the production of crops for world markets. By the end of the summer a financial crisis had ensued (Clain-Stefanelli and Clain-Stefanelli 1975). European financial failures and American "get-rich quick" speculation overstrained the economy and in August 1857, the Ohio Life Insurance and Trust Company was forced to close its doors which marked the beginning of a series of nearly 5,000 bank and other commercial failures which has come to be known as the Panic of 1857.

The loss of the *Central America*'s gold shipment has been credited with exacerbating the financial panic of 1857 which continued to grip the country until the Civil War. William Tecumseh Sherman wrote, " The absolute loss of the treasure went to swell the confusion and panic of the day." (Sherman 1875). Sobel (1973) reported that New York banks showed deposits of \$67.4 million on 8 August 1857 but these had fallen to \$57.3 million by 12 September. He further noted that many banks were on the verge of bankruptcy but they held on. They expected that the next gold shipment from

FIGURE 31. Herndon Monument, U.S. Naval Academy, Annapolis, MD. A plaque on the monument states: "Commander William Lewis Herndon, 1813-1857, Naval Officer – Explorer – Merchant Captain. In command of the *Central America*, home-bound with California goldseekers, Captain Herndon lost his life in a gallant effort to save ship and lives, during a cyclone off Hatteras, September 12, 1857. 'Forgetful of Self, in his death he added a new glory to the annals of the sea'– Maury."

California, due later that month, would end the panic in New York. The news of the *Central America*'s sinking: ". . . hit the financial community as a blow to the heart. Now the bank failures began, not only in New York, but throughout the nation." (Sobel 1973).

Van Vleck (1967) placed less emphasis on the financial impact of the sinking. He pointed out that on 15 September 1857, "in the midst of news of extreme stringency in Philadelphia, Cincinnati, and Chicago, the newspaper revealed that the steamer *Central America*, en route from Aspinwall to New York City with $2,000,000 in gold aboard, was unreported and overdue." With this news, "the market declined under feverish trading, and money went to unheard-of rates." On 17 September, word was received that the *Central America* had sunk, "a calamity which, aside from the heavy toll of human life, amounted to a total loss, including gold in hands of passengers and the value of the ship, of about $2,500,000. There was no insurance on the vessel, and only $500,000 of the gold had been covered. Excitement ran high, but the market stood the shock fairly well, declining only slightly during the next few days." The estimated value of the ship at the time of the sinking was $140,000 (Ridgely-Nevitt 1944).

METHODS

The shipwreck site of the SS *Central America* was discovered within the Harrington Hill Quadrangle of the North Atlantic Ocean (31-32° N, 76-78° W; 1:250,000 scale). It was imaged with side-scan sonar in 1986, at a depth of 2,200 m on the shoreward portion of the Blake Ridge (Fig. 32). Site verification studies were undertaken in 1987 and investigations of the site were conducted during 1988 to 1991 from the R/V *Arctic Discoverer*. *In-situ* observations were made with the unmanned research submersible *Nemo*. This vehicle was equipped with video and still cameras, sampling manipulators, and storage compartments for the collection of specimens. The following section discusses the methods used to discover and investigate the shipwreck.

DISCOVERY METHODOLOGY

Historical Documentation

More than 1,500 articles appeared in over 200 nineteenth-century newspapers that chronicled the loss of the SS *Central America*. Historical accounts by Andrist and Hanna (1961), Barrows (1897), Bode (1972), Chidsey (1968), Conrad (1988, 1991), Corbin (1888), Coulter (1970), Duhse (1990), Dunbaugh and Thomas (1989), Hastings (1955), Heite (1966), Herdendorf (1991), Herdendorf and Conrad (1991a, b; 1993), Heyl (1953), Holiday (1981), Jensen (1969), Johnson (1974), Kemble (1943), Klare (1992), Lewis (1949), Lincoln (1911), Manlove (1915), Martinez (1990), Maury (1857), Mitchell (1986), Noonan (1992a), Paul (1947), Perry et al. (1857, 1858), Ponko (1974), Ridgely-Nevitt (1944, 1981), Root and Connelley (1901), Sherman (1875, 1909), Sobel (1973), Stampp (1990), Van Vleck (1967), Webb (1895), and Wiltsee (1938) provided a rich published record of the SS *Central America* and her era. Letters, diaries, logs, and other unpublished documents from the 1850s were also reviewed for information about this steamer. Over 250 libraries in the U.S. and overseas supplied useful information. Materials graciously provided by 102 descendants and relatives of passengers and crew on the ill-fated voyage were particularly insightful.

Using the observations of survivors and other eyewitnesses to the disaster, all pertinent data were organized into a correlation matrix (Table 7). A column in the matrix corresponds to a single account of the tragedy. The rows represent three-hour intervals beginning with the onset of the storm and ending when the rescue efforts were discontinued. An entry at a given row and column thus gives a summary of what was happening at that time, according to the person represented by that column. The matrix facilitated account comparison and made it possible to develop a more complete understanding of the sequence of events leading to the sinking. This information, coupled with knowledge about the design and construction of wooden-hulled steamships, the methods used for ocean navigation in the 1850s, and the ocean/atmospheric physics in the region of the sinking served as the database used to search for the shipwreck.

Search Theory

In 1985 Dr. Lawrence D. Stone of Metron, Inc., working in conjunction with members of Columbus-America Discovery Group, developed a probability distribution

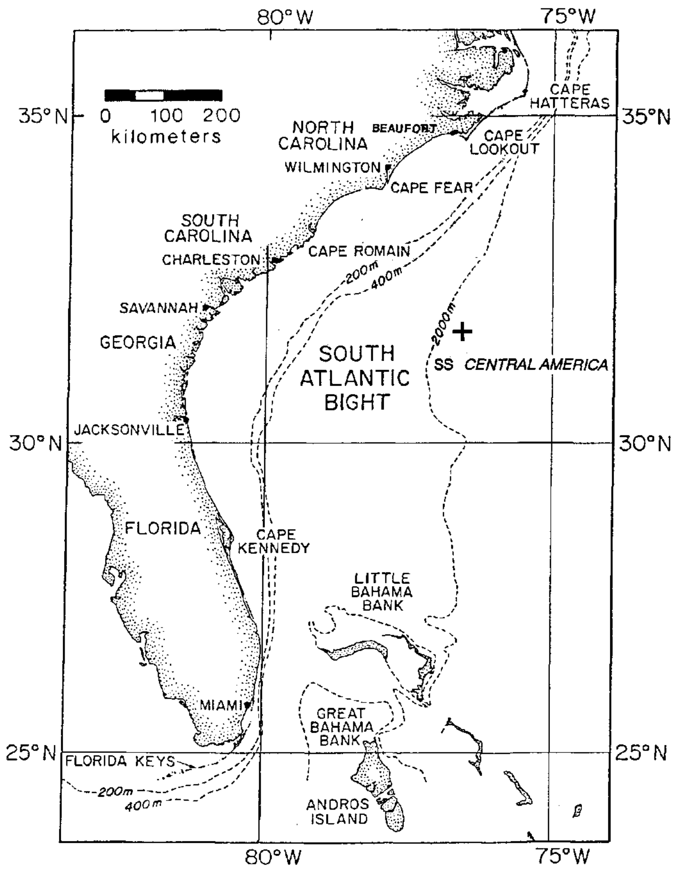


FIGURE 32. Map of the South Atlantic Bight, showing location of the SS *Central America* shipwreck. Depth contours are given in meters. Base map after Brooks and Bane (1983).

TABLE 7

A small example portion of the data correlation matrix.

	James M. Frazer *Second Officer*	**Judge Alonzo Castle Monson** *First Cabin Passenger*	**Mrs. Virginia Birch** *First Cabin Passenger*
Friday SEPT 11 AM 12:00			
3:00	At 4:00 came up on deck. Wind was blowing NNE. Sea was running high with heavy rain.		
6:00	Weather continued to increase till 8:00 when it blew a violent gale from the NNE. At 8:00 no rain but still blowing heavy. Location 31 45N; 78 15W about 95 miles east off Cape Roman and 127 miles south 1/2 west off Cape Fear off Carolina coast.		On Friday morning the vessel careened over on her starboard side and we heard the seams crack.
9:00	Storm spencer was set at 10:00 but was blown away. The gale and sea were now increasing, ship was so high out of water we could not bring the ship head to the wind.		
PM 12:00	At 12:00 the ship kept course but was retarded by wind. Gale increased till noon. Wind hauling northward and westward and by 12:45 to 1:00 was driven off her course to SE, falling off into the trough of the sea. At 2:00 drag was put over, first 40 to 50 fathoms then 90 to 100 fathoms. 9 inch hawser. But to no avail. Not as much sea as in forenoon.	Shortly before 1 PM, requested by Garrison and Captain Herndon to assist with bailing. At 1 PM last table set for Steerage passengers.	On Friday the gale increased to a hurricane (78 knots) and the vessel sprung a leak during the day. Gangs of passengers formed to bail the vessel.
3:00	At 5:30 the ship was still in trough of sea. Captain ordered Badger and me to cut away foremast. Listed to the leeward.	About 3 PM men set about bailing. "On Friday afternoon, Captain Herndon came to my stateroom and asked permission to remove his instruments there..."	
6:00	After the foremast was cut away, drag was let out to 90 fathoms but to no avail.		All Friday night the gentlemen were bailing.
9:00	About 9:00 or 10:00 water seemed to be at a standstill, but then seemed to gain faster than ever.	Assisted with bailing all night.	
Saturday SEPT 12 AM 12:00	Day began with very heavy gale and hazy horizon, some rain but not so much sea as previous day.		
3:00	At 5:00 or daylight wind was west. At 5:45 cut starboard anchor (2-1/2 ton)		
6:00	At 6:00 wind was blowing heavy and in squalls hauling to the southward, northward, and westward.	Shortly after daybreak on Saturday morning the clouds cleared away somewhat. At approximately 8 AM Captain Herndon went to Monson's stateroom to return his instruments to their cases. He stated that there was no hope unless the storm abated.	
9:00	Midday sighted *Marine*.		
PM 12:00	Weather moderated very much. The wind SW. Shortly afterward saw brig standing down on us. At 2:00 lowered away ship's boats and began transferring women and children.	At half past one a sail was seen in the distance. Five boats available.	On Saturday at 12:00...a brig was seen some little distance...bore down toward us.
3:00		After women and children were on boats, he boarded small boat with Mr. Priest et al. "As we started for the brig the distance was two miles. By the time we reached her the distance was three miles. It took an hour and a half to reach the brig." On board, "In about a half hour a small boat came," with Ashby on board. The boat started again for the steamer. Shortly two boats came up, passengers and firemen aboard.	
6:00	Fired rockets and saw boat on starboard bow but would not return hail. Turned out to be boatswain's boat. One hour before sunset, schooner sighted. Few minutes after 8:00 boat took water on deck and sank.	Schooner's and steamer's lights visible. "Shortly afterward the steamer's lights disappeared."	All who were rescued were on board by 6:00. Towards evening we saw a schooner close... it soon became dark.
9:00	After 20 minutes in water I noticed light to the eastward. The wind was then about SW. Was picked up shortly thereafter by *Ellen*.	Two hours later the boatswain's boat returned with the news of the sinking.	We lay by the steamer all night.

map for the location of the SS *Central America* that was used to construct a search plan for the shipwreck. The technique used to develop the distribution map was based on a combination of historical, statistical, analytical, and subjective methods (Stone 1992). The approach used by Dr. Stone and the Group and the results of their analysis are summarized below.

Analysis of the historical record showed that four positions were determined by seamen in the vicinity of where the *Central America* sank in the hours preceding and following the sinking (Fig. 33). The sinking took place shortly after 8:00 PM on Saturday, 12 September 1857. On Saturday morning around 7:00 AM, Capt. Herndon took a celestial fix using a lunar meridian (the high point of the moon above the horizon for that day), perhaps during the passage of the hurricane's eye when the sky cleared for a brief period. At 6:30 PM the schooner *El Dorado* approached the *Central America* and Capt. Herndon was able to verbally pass to the *El Dorado*'s first mate, G. Sherlock, what is believed to be his ship's position at the time of the lunar meridian (31° 25' N, 77° 10' W). The second position came from Capt. Hiram Burt of the brig *Marine* when he first sighted the *Central America* at 12:45 PM on Saturday, several kilometers off his lee bow to the east-northeast. He reckoned his position (31° 40' N, 76° 50' W) based on a celestial fix he had made on Friday morning at 6:00 AM. The third position was determined by Capt. Anders Johnsen of the Norwegian bark *Ellen* at 8:00 AM Sunday while rescuing survivors of the shipwreck. He also took a celestial fix using a meridian of the moon (31° 55' N, 76° 13' W). The fourth position was an estimate of the wreck's location by Capt. Thomas W. Badger, a passenger on board the *Central America* who was rescued by the *Ellen* (31° 50' N, 76° 15' W).

One additional position aided in determining the set of the current following the sinking. Eight days and 20 hours after the disaster three men were found in a

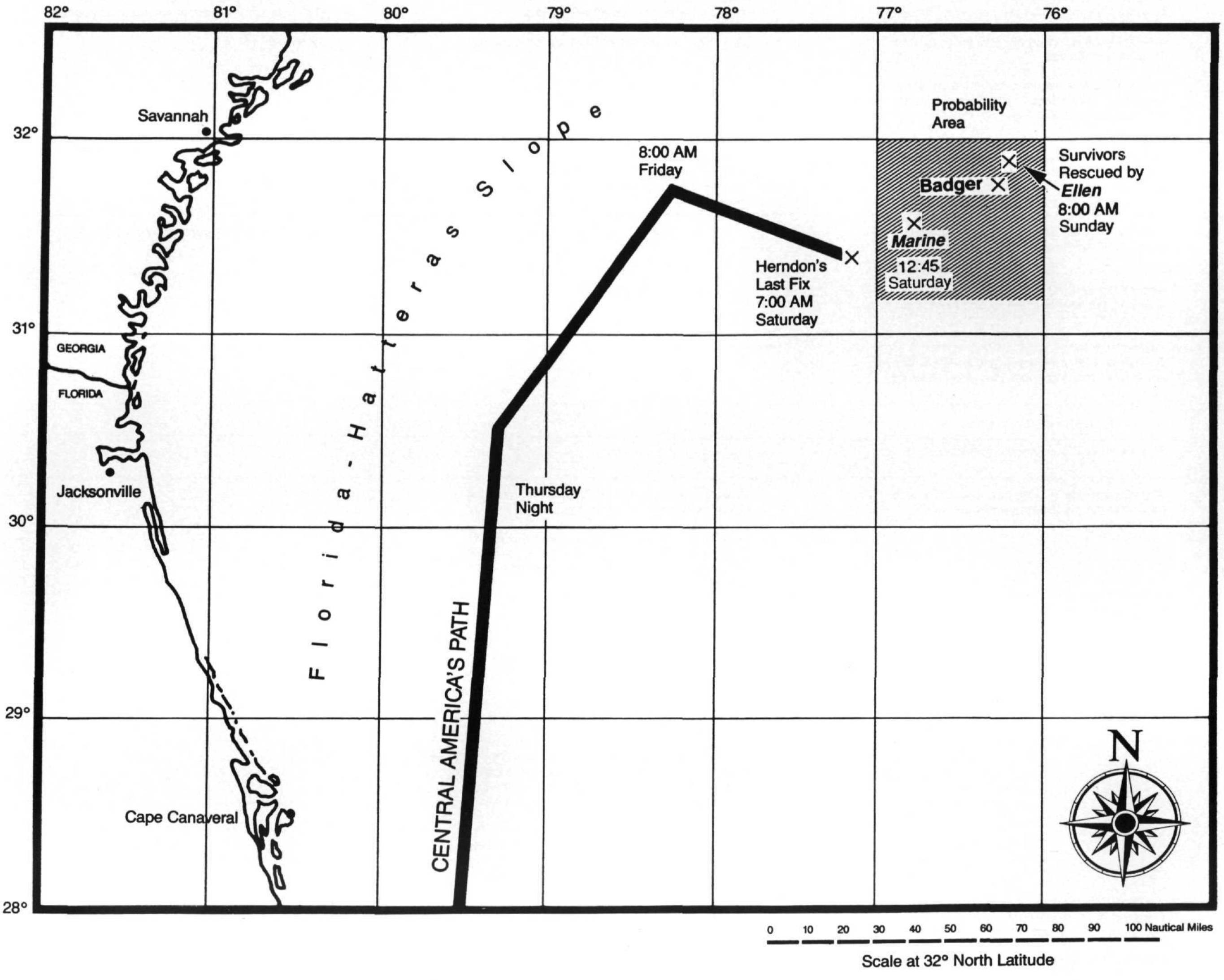


FIGURE 33. Solid line shows the route of the SS *Central America* during her last voyage. The line terminates at the position relayed by Captain Herndon to the schooner, *El Dorado*, one-and-one-half hours before the *Central America* sank. Also shown are the estimated positions of the brig *Marine* when she sighted the *Central America* at 12:45 PM on the day of the loss and the bark *Ellen* at 8:00 AM the next morning as she was recovering survivors. Near the *Ellen* position is the location of the shipwreck as estimated by Captain Badger, a passenger on the *Central America* who was rescued by the *Ellen*. After Stone (1992).

battered lifeboat, barely alive, by the English brig *Mary* over 725 km northeast of the sinking (Maury 1857). Capt. Shearer of the *Mary* estimated the position of the rescue as 36° 40' N, 71° 00' W. They were apparently transported by the Gulf Stream at an average speed of 3.7 km/hr (2.0 knots).

Probability Maps

To estimate the location of the shipwreck, several steps were required once the relevant historical data had been assembled. These included: 1) organizing the information into self-consistent clusters, each of which became a scenario that was used to provide an estimate of the shipwreck's location, 2) quantifying the uncertainties in the information for each scenario in terms of probability distributions, 3) running a Monte Carlo simulation (Kendall 1976) using these probability distributions to compute a probability map as the estimated location of the shipwreck resulting from each scenario, and 4) assigning relative credibility to each scenario and producing a composite probability map that was the weighted sum of the probability maps for each scenario. The three scenarios that evolved from this approach were designated: 1) the *Central America* scenario based on Herndon's celestial fix, 2) the *Marine* scenario based on Burt's dead reckoning position, and 3) the *Ellen* scenario based on Johnsen's fix.

For the *Central America* scenario, such factors as the accuracy of the fix taken 13 hours before the sinking and the drift caused by the effects of the wind on the ship (leeway) during that period had to be modeled. For the *Marine* scenario, the uncertainty in Burt's reckoned position had to be considered. In the case of the *Ellen* scenario, the approach was to drift the survivors backward to the time of the sinking to obtain an estimate of the position of the shipwreck. A person in the water had no leeway, so drift was determined solely by the projected ocean current. A computer model of wind-driven currents yielded speeds of 0.2 to 0.4 knots during the storm in addition to the general northeast flow of the Gulf Stream as indicated by the drift of the final survivors in the lifeboat. Prof. Roland W. Garwood of the Naval Postgraduate School, Monterey, CA, developed the model and produced estimates of the wind-driven component of the current.

Once these uncertainties were estimated, probability maps were created for each scenario based on a Monte Carlo simulation. Using this method the behavior of a system can be simulated by entering values of the variables, and repeating the operation over different sets of values to explore the system under a variety of conditions. For each scenario, random sampling was used to draw 4,000 points to represent the position of the *Central America* at 7:00 AM Saturday, the *Marine* at the time of the first sighting (12:45 PM Saturday), and the position of the *Ellen* at 8:00 AM Sunday. These points were obtained by making 4,000 independent draws from the bivariate normal distribution representing the air in each fix and adding this air to the reported position. From these positions, currents and wind effects were applied to produce 4,000 independent locations. Assuming that the ship sank straight to the bottom, a 4-nautical mile square grid was established for the ocean bottom. The number (N) of points falling into each cell was computed and the probability (P = N/4,000) was assigned to that cell. Next, the three separate scenarios were subjectively weighted to produce the composite probability map used for planning the search (Fig. 34). The relative credibility thus assigned to the three scenarios were: *Central America* (23%), *Marine* (5%), and *Ellen* (72%).

Sonar Search

Utilizing the composite probability map, Fred Newton of Triton Technology, Inc. developed a search plan designed to produce a high probability of detecting the *Central America.* The plan consisted of 11 long straight legs that covered a parallelogram encompassing most of the probability map (Fig. 34). The first leg was in the center of the parallelogram (highest probabilities) with subsequent legs working their way outward until the entire survey area was mapped. A SeaMARC IA (International Submarine Technology, Ltd.) side-scan sonar system was selected for the survey. The SeaMARC IA is a high-resolution swathmapping system designed to operate at full ocean depths. It consisted of separate port and starboard side-scan sonars that operated at frequencies of 27 and 30 kHz, a 600-kg, 4.6-m long towfish, and a digital data acquisition and processing system (Wright 1988). The towfish carried port and starboard side-scan arrays which were capable of imaging a swath of the seafloor from 500 to 5,000 m wide. The sonar was operated by towing the "fish" about 75 m above bottom via a long coaxial cable (3 to 5 km) from a surface research vessel. Side-scan sonar data were displayed on paper in real time as orthorectified images in which the geometric distortion from slant range and vessel speed changes had been eliminated. At the same time, digital data were stored on an optical disc for further processing and image enhancement. Positioning and navigation during the survey were accomplished by using Loran C and transit satellites fixes.

The sonar survey was conducted in June and July 1986 in conjunction with Williamson & Associates, Inc. of Seattle, WA, operator of the SeaMARC IA system which was owned by International Deep Sea Survey, Inc. Target models were developed based on anticipated conditions of the *Central America* after 130 years of submergence. Because of the uncertain nature of the extent of degradation, several alternative models were proposed. Early in the search, the sonar produced two promising contacts (designated as Sites A-2 and H) located southwest of the *Ellen* position in cells having probabilities as high as 56 x 10^{-3} of containing the *Central America* (Fig. 34). The attributes of the contacts appeared to match those predicted by target models and the contacts were in high probability areas. These facts suggested that the remainder of the sonar search be terminated but it was decided to follow the original plan and complete the survey. This took a total of 40 days to cover approximately 3,600 km^2 of ocean floor. The survey produced over 100 contacts which appeared to be

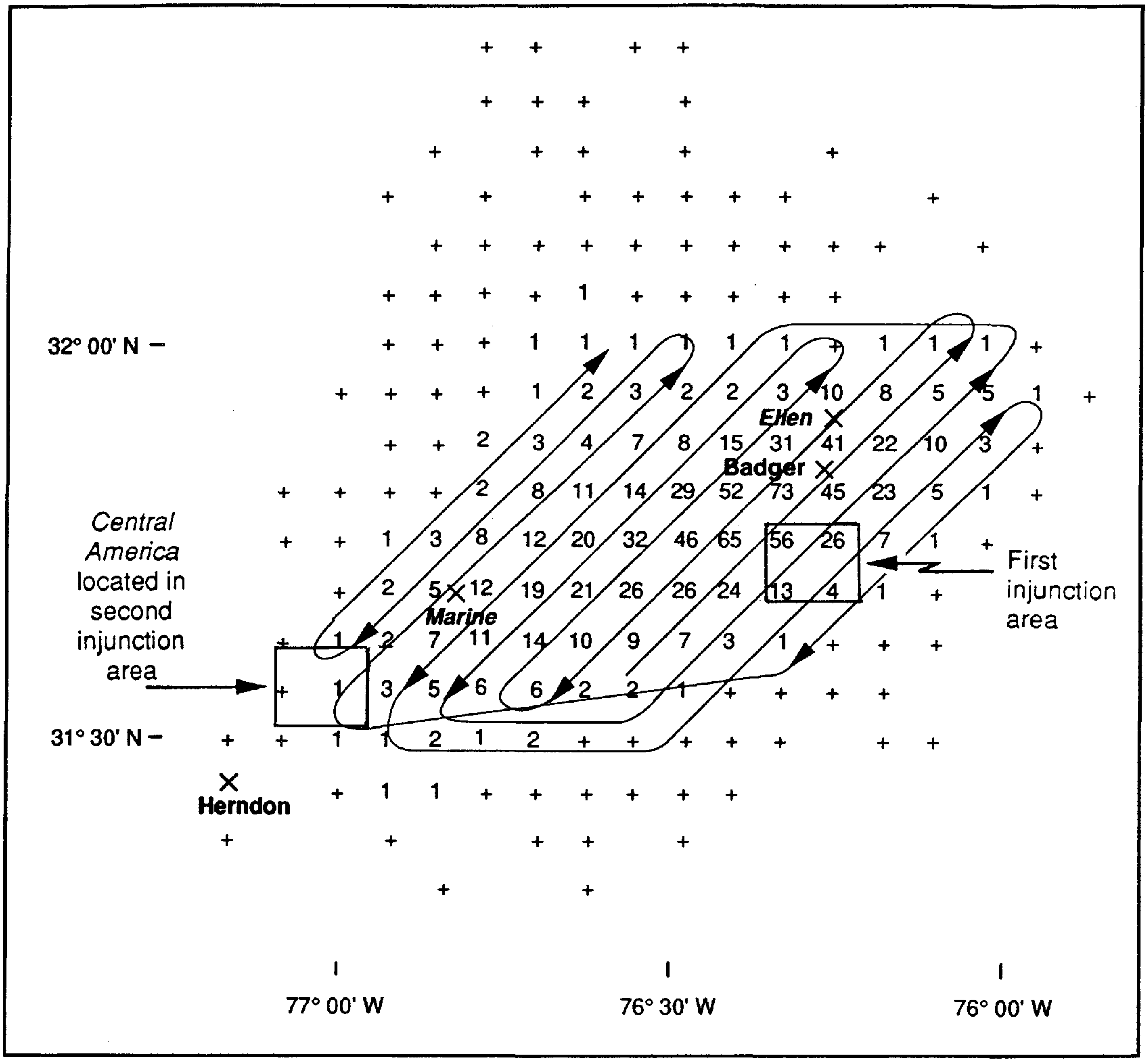


FIGURE 34. Composite probability map for the location of the *Central America*. The map represents the weighted average of the maps for the *Central America*, *Ellen*, and *Marine* scenarios. The number in a cell is the probability that the shipwreck is in that cell multiplied by 1,000. The Xs indicate the positions given by Herndon, *Marine*, *Ellen*, and Badger that are shown in Fig. 33. Superimposed on the composite probability map is the search plan that found the *Central America*. The plan consists of long straight paths with arrows indicating the direction of motion. The plan starts near the bottom center of the figure, searches the high probability areas first, and then works its way out to the lower probability areas. The first and second injunction areas are shown on the composite probability map. The promising first shipwreck was found in the first injunction area and was investigated during 1987. The location of the *Central America* was confirmed in the second injunction area in 1988. After Stone (1992).

cultural deposits (e.g., shipwrecks and other man-made objects). Several of these were of the size and configuration to be possible shipwrecks but the most promising ones continued to be the two early contacts mentioned above.

Site Verification

The following summer, 1987, the Group returned to the survey area to conduct verification studies with a prototype of a remotely controlled underwater vehicle (see the following description of the research submersible *Nemo*). The submersible was equipped with cameras (video and still) and a robotic arm. Visual surveys were conducted of the contacts at Site A-2 and Site H, as well as three other sites (D-1, D-2, and D-3). The first four contacts proved to be the wrecks of wooden-hulled ships and the last was a metal shipping container (Site D-3). An uncontrolled photomosaic was made of the shipwreck at Site D-2; at 20 m long and 8 m wide, it was small and it lacked the coal signature attributes expected for the *Central America*, as did the shipwrecks investigated at Sites A-2 and D-1 (Fig. 35). At Site H, however, a number of artifacts were recovered which included a 450-kg anchor, lumps of coal, pieces of iron, ceramics, and pottery dating from

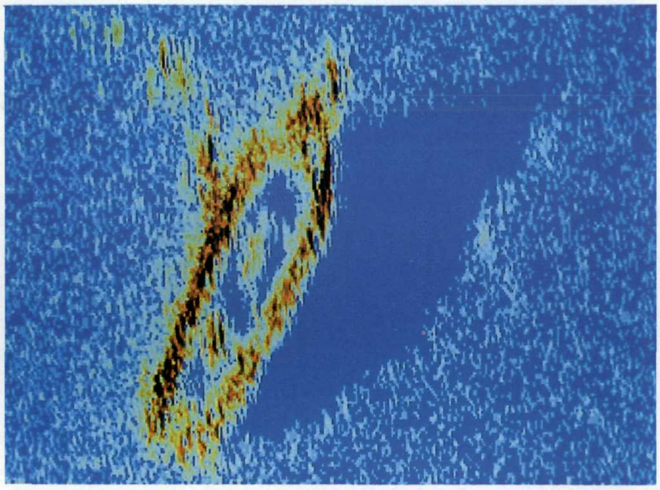


FIGURE 35. Side-scan sonar image of a sunken ship at Site D-1. A SeaMarc 1A side-scan sonar system was used to map the survey area. This system sends out a wide swath (up to 5 km) of sound waves which bounce off objects on the seafloor. As the waves bounce back, they are interpreted by a computer to create an image of the seabed. The side-scan sonar images (sonograms) were computer enhanced and colorized to aid in target recognition. The survey produced a number of promising contacts, such as the one illustrated here. The outline of a wooden hull is clearly visible, as well as, a mast which projects forward across the port bow. However, the interior of the hull lacks the coal signature anticipated for the *Central America*. The dark area off the starboard side of the ship is a shadow produced as a consequence of sonic impulses directed toward the port side of the ship.

1854 (British registry mark impressed on the bottom of a saucer), and articles belonging to women and children. Some of the artifacts (boiler coal) were airlifted to the U.S. District Court in Norfolk, VA, and under admiralty law an injunction was obtained for exclusive rights to explore and recover the shipwreck (Fig. 34). However, by the end of the 1987 field season, no conclusive evidence had been obtained that verified the wreck as the *Central America*.

Over the winter of 1987-1988 the Group continued to review the side-scan sonar data with improved, image-analysis software. This analysis showed that one of the contacts (Site FA) found during the ninth leg (in a cell with a probability of only 1×10^{-3}), had the right configuration and displayed texture similar to that produced by the coal pile found at Site H. The Group decided to investigate Site FA on their way back to continue exploration of Site H. On 11 September 1988, on the first pass of the submersible over Site FA, the video transmission revealed two large side wheels (Fig. 36) and massive engineworks (Fig. 37). To confirm the identity of the shipwreck, the Group searched for the ship's bell. It was found half buried in sediment ooze within the wreckage (Fig. 38). The 125-kg bronze bell was carefully excavated with *Nemo*'s manipulator, dusted with a broom in an attempt to read the inscription, placed in a recovery module which was secured against the

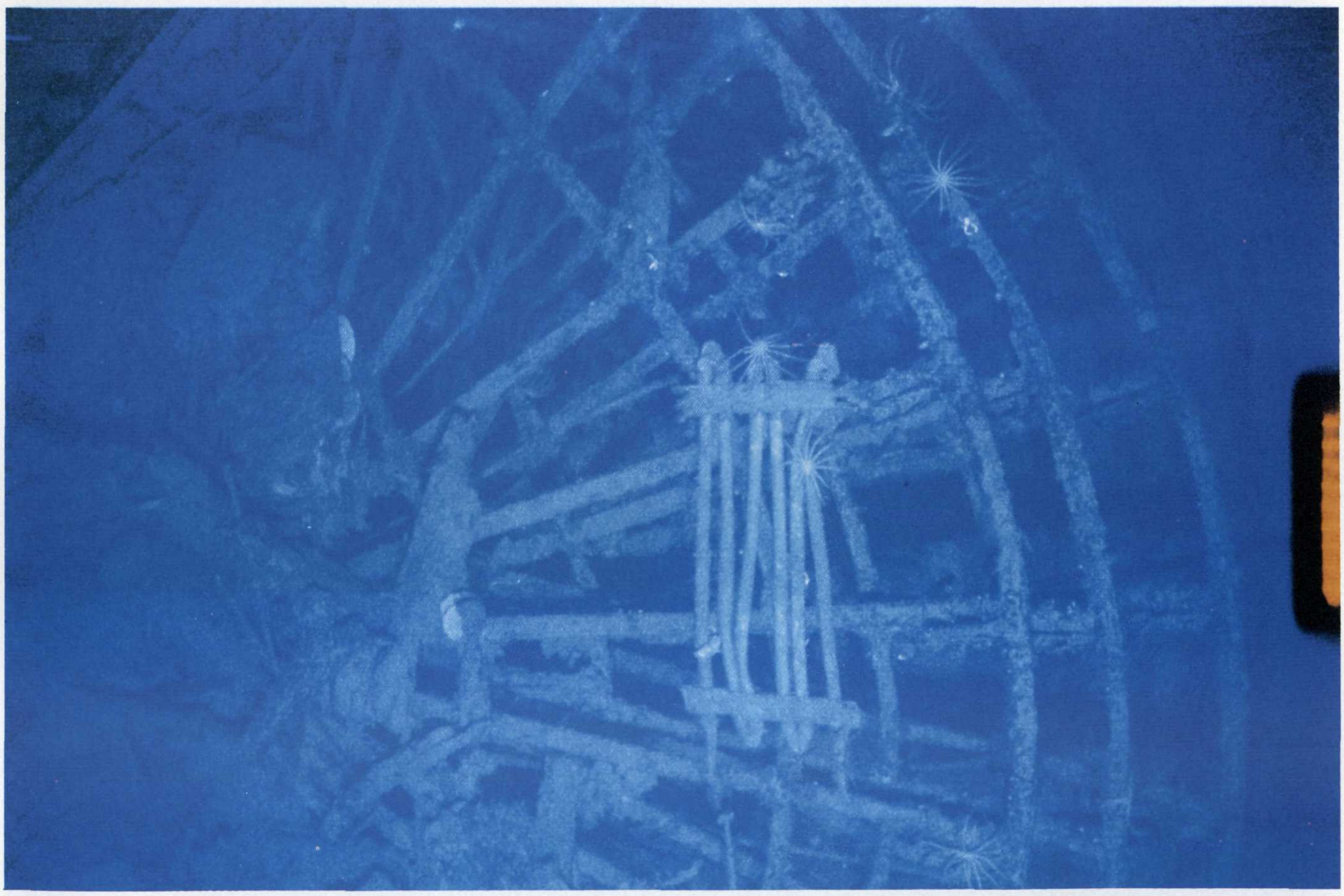


FIGURE 36. Port side wheel of SS *Central America*. This image confirmed that the shipwreck was a side-wheel steamer of the nineteenth century. The looped tubing near the center of the photograph is thought to be a de-icing device. Brisingid sea stars and galatheid crabs abound on the elevated ironworks.

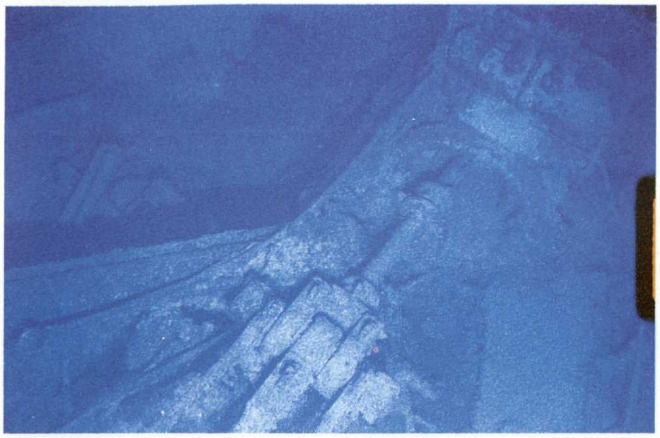


FIGURE 37. Engineworks of the SS *Central America.* The engineworks are "in place" on the shipwreck between the two side wheels. A cylinder (upper right), cylinder rod (center), and cross head-connecting rod assembly (lower center) can be seen in this view. Compare this photograph with the engineworks drawing in Fig. 11.

undercarriage of the submersible, and lifted to the surface (Fig. 39). On board the *Arctic Discoverer*, the raised letters on the bell were easily legible: *MORGAN IRON WORKS – NEW YORK – 1853* (Artifact No. 8004). The *Central America's* engines and other ironworks were fabricated and installed by this company in 1853. Soon after, gold ingots and coins located in the wreckage provided further confirmation that Site FA was the *Central America* (Fig. 40). Following these discoveries, a second injunction was obtained for recovery at Site FA (Fig. 34).

As concluded by Stone (1992), in hindsight it was apparent that the *Central America* scenario, based on Capt. Herndon's position, was the most accurate of the three. Herndon was highly respected as a careful seaman and an excellent navigator. It appeared that he was able to take a more accurate celestial fix on a sinking ship in the midst of a storm than the captain of the *Ellen* did after the storm had cleared and his ship was out of danger. Even though the *Central America* was found in a cell with low probability, the plan worked—the shipwreck was found within the predicted probability envelope and the budgeted search time.

TECHNOLOGY DEVELOPMENT

Surface Research Vessels

The data, specimens, and artifacts discussed in the present paper were collected during the period 1986 to 1991 aboard the motor vessel (M/V) *Pine River* (1986), research vessel (R/V) *Nicor Navigator* (1987), and R/V *Arctic Discoverer* (1988 to 1991). The *Pine River* was used to conduct the side-scan sonar survey and the *Nicor Navigator* was used to investigate promising targets. All investigations conducted directly on the shipwreck of the

FIGURE 38. The ship's bell partially buried in sediment ooze. The objects at the far left resemble steam whistles. Two brisingid sea stars can be seen at lower left of photograph. The measuring staff at far right is divided into 50-cm segments.

FIGURE 39. Recovering the ship's bell of the SS *Central America*. The 125-kg bronze bell is being carefully excavated by *Nemo*'s manipulators. A band near the top of the bell carries the raised inscription: *MORGAN IRON WORKS – NEW YORK – 1853*. The SS *Central America*'s engines and other machinery were fabricated and installed by this company in 1853 (Artifact No. 8004).

SS *Central America* were undertaken from the R/V *Arctic Discoverer* (Fig. 41).

The R/V *Arctic Discoverer* was launched as the Canadian Coast Guard Ship *A. T. Cameron* in June 1958 at the shipyards of Milne, Gilmore, and German Ltd. in Montreal, Quebec. The vessel was designed along the lines of a typical British trawler of that period but heavier plating and framing were added to render it serviceable for the ice conditions in the far north Atlantic. She was named for Dr. Alexander Thomas Cameron, one of Canada's foremost fisheries scientists of the early 1900s. For 25 years the *Cameron* was operated by the Fisheries Research Board of Canada as a side trawler to assess the strength of fish stocks off Newfoundland and to collect oceanographic data. The advent and wide use of stern trawlers hastened the end of the *Cameron's* service in fisheries research. In 1985, she was sold to Alexander Bay Shipping Ltd., of Glovertown, Newfoundland. As is the procedure with government-owned vessels, the name *A. T. Cameron* was retired when the vessel was sold and the new owners renamed the ship M/V *Arctic Ranger*. She was intended to be used in the annual white-coat seal fishery on the northern ice floes. In the mid-1980s a successful anti-seal hunt campaign by Greenpeace and other animal welfare groups drastically reduced the market demand for seal pelts. Thus, funds were not available to convert the ship to a sealer and in 1988 she was again sold, this time to Columbus-America Discovery Group of Columbus, OH. Under the new name R/V *Arctic Discoverer* and the command of Capt. William Burlingham, she served as the primary surface vessel for the SS *Central America* expedition.

FIGURE 40. Gold bars and coins resting on collapsed timbers of the SS *Central America* shipwreck.

The *Arctic Discoverer* was 55 m in overall length with a 10-m beam, 4.4-m draft, and a gross tonnage of 753 (Fig. 41). The main engine was an Alpha 1,000/1,100 BHP (variable pitch propeller), capable of a cruising speed of 12 to 13 knots at 305 rpm. Auxiliary engines included bow and stern outboard thrusters each with 360° turning capability (Fig. 42). The thrusters, which were linked to the satellite navigation system, were used to maintain position over the shipwreck site, 2,200 m below. Other specialized facilities included an articulating crane designed to launch and recover a 6-ton submersible, and a specialized control room with 17 video screens and interactive systems to monitor the seafloor and direct the submersible. During the expedition, the *Arctic Discoverer* participated in the National Weather Service Voluntary Observing Ship Program, collecting, recording, and transmitting meteorological and sea-state data every six hours.

Research Submersible

All of the seafloor observations and collections reported in the present paper were made with the remotely operated, 6-ton research submersible *Nemo* (Fig. 43). First assembled in Columbus, OH, in 1987, *Nemo* was designed to conduct delicate operations in an extreme cold, high-pressure, and corrosive environment and at complex wooden shipwreck sites. With robotic arms and precision tactile manipulators (Fig. 44), *Nemo* retrieved items smaller than one centimeter and as large as the *Central America's* 125-kg bell. Other specialized tools included a hydraulic sampler to dislodge and carry specimens (Fig. 45), a water jet to remove sediment and debris, a suction picker (cup device with a vacuum line in the center) to recover fragile artifacts (Fig. 46), and a suction dredge to sample unconsolidated bottom material (Fig. 47). A silicone rubber injection system was developed to retrieve loosely cemented artifacts as a unit (e.g., stacks and piles of gold coins) so that their relative position could be preserved and their surfaces protected from damage. In one instance a "tower" of about 300 coins was recovered in a single block of silicone

FIGURE 41. Research vessel R/V *Arctic Discoverer*. In 1988, Columbus-America Discovery Group acquired the *Arctic Discoverer*, a former Canadian fisheries research vessel. She was well suited for deep-ocean work but considerable modification was required to adapt her for the specialized task of recovering a nineteenth-century steamship. Thrusters, cranes, winches, and a "high-tech" control room were added. The *Arctic Discoverer* is 55 m long, 10 m wide, 753 gross tons, and 4.4 m in draft. She is powered by a 1,000 hp diesel engine that yields a cruising speed of about 12 knots.

(Figs. 48–51). *Nemo* was also equipped with storage compartments which were used for transporting tools and experiments to the ocean floor and for recovering artifacts and specimens (Fig. 52). *Nemo*'s multiple cameras, illuminators, and booms, which were used to record the entire deep-sea investigation, are discussed below. All images, including three-dimensional views, were transmitted via fiber-optic cable to the control room (Fig. 53) aboard the R/V *Arctic Discoverer*, which permitted scientists and engineers directing the dive to have "telepresence" (ability for an observer to have a presence at a remote location via television transmission) on the ocean floor as well as underwater depth perception from the stereo images.

The general lack of a strong current at the wrecksite led to poor visibility when the bottom was disturbed. Manipulation of the shipwreck features usually caused suspension of fine particles and silt in the surrounding water column. The Group employed a device known as a "silt prop" to improve visibility. The silt prop was mounted on the end of a boom which was swung out from the top of *Nemo* and positioned over the working area. The silt prop was then used like a ceiling fan to bring down a continuous column of clear water from above to flush the work area and maintain high visibility. In certain situations water current was used for excavation. *Nemo*'s front thruster was used to create a moderate current which was capable of suspending sediment which had buried some of the shipwreck features.

FIELD INVESTIGATIONS

Site Navigation and Mapping

Precision navigation of the submersible and site mapping were accomplished through a network of sonar transponders set around the perimeter of the shipwreck site. The transponders were deployed at the four corners of an approximate square (1,500 m on a side). This permitted the position of a fifth transponder, mounted on *Nemo*, to be established. In this way, an acoustical grid was formed which allowed the position of artifacts to be determined within a few centimeters when combined with optical ranging from *Nemo*'s cameras. Using any three of the perimeter transponders, the acoustic triangulation results were highly repeatable and accurate to ± 0.1 m. Each season necessitated a new deployment and recovery of transponders. The components of each transponder station consisted of a float (subsurface buoy), a suspension line connecting the float to the transponder unit, the transponder, an anchor line, and an anchor.

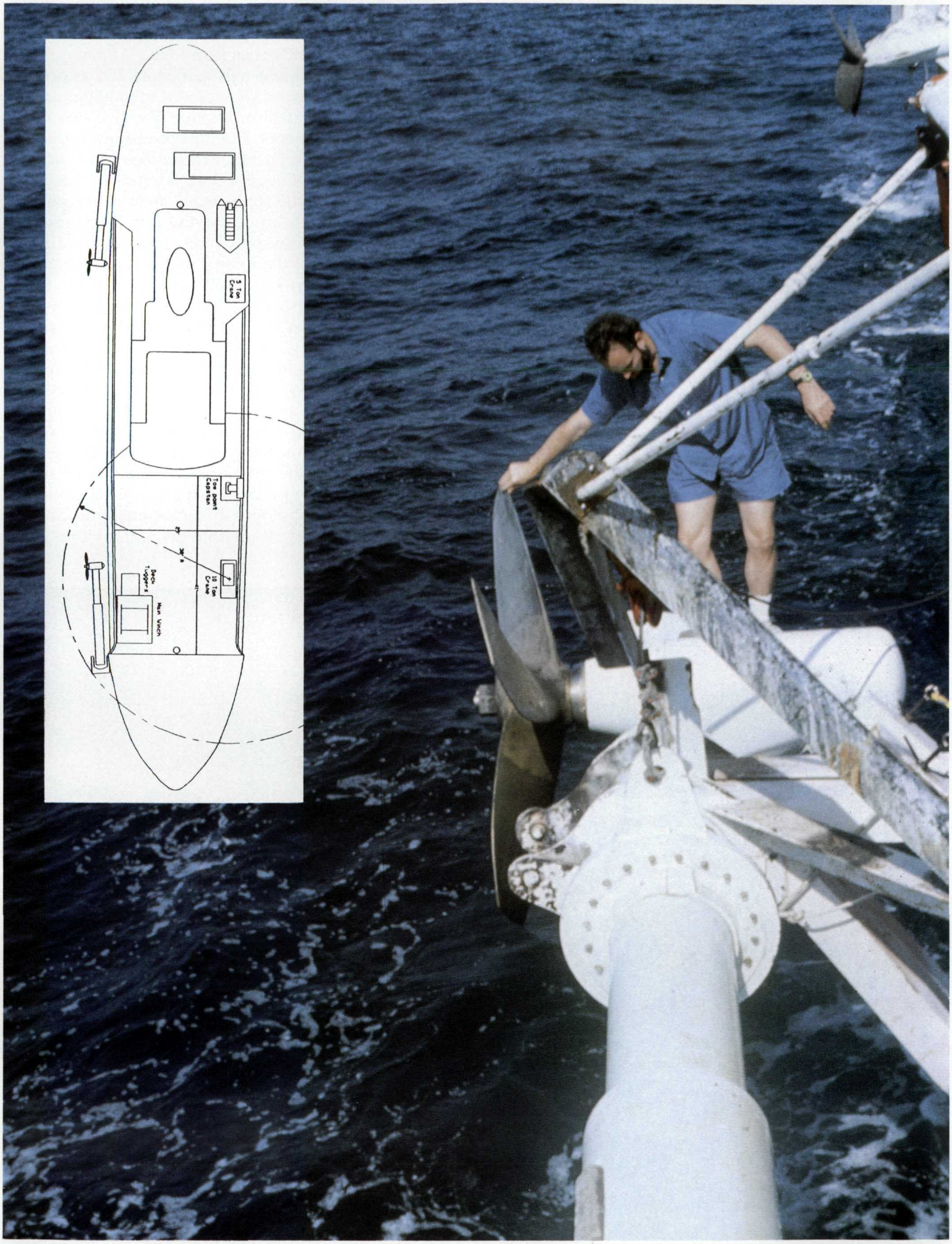


FIGURE 42. Outboard thruster on board the *Arctic Discoverer* used for dynamic positioning. Driven by auxiliary engines installed on the aft deck, bow and stern thrusters were used to maintain position directly over the shipwreck site 2 km below. Each thruster is omnidirectional and linked by a computer to a satellite navigation system. Position of thrusters and launch crane shown on inset.

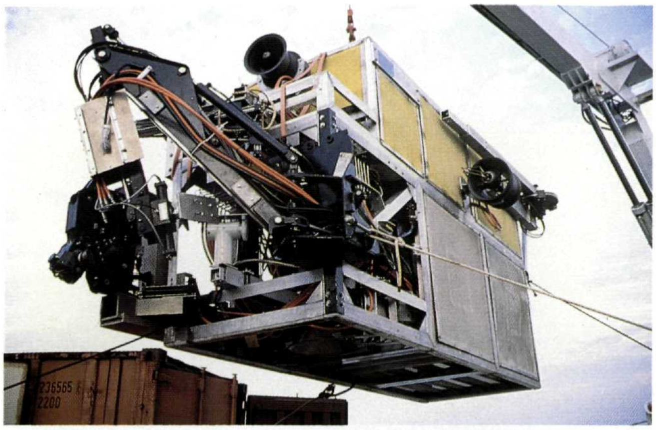


FIGURE 43. The research submersible being loaded aboard the R/V *Arctic Discoverer. Nemo* is an unmanned, remotely controlled submersible capable of precise deep-ocean navigation and recovery of items from the seafloor. Cameras and sampling devices were installed on the submersible once it was on board the research ship. Inspired by Jules Verne's legendary captain, *Nemo* was designed by Columbus-America Discovery Group and constructed in Columbus, OH, in 1987.

Video Observations and Photographic Record

In order to obtain high-quality images of the ocean floor the submersible was fitted with broadcast-quality video cameras, 35-mm still cameras, booms, pan-and-tilt mechanisms, and powerful lights (Fig. 54). Video equipment included five 3-chip color cameras, two 2-chip color cameras, and three black-and-white cameras. There were also three 35-mm still cameras (250 exposures each). All of the cameras were placed in modified marine housings rated to 3,000 m depths. The five broadcast-quality video cameras (3-chip) were mounted on telescoping booms with either hydraulic or electric pan-and-tilt controls. The main boom, located in the center forward portion of the submersible, held three cameras, one for 35-mm stills and two video units mounted in such a way as to transmit stereo images. By a slight lateral movement of the boom, successive photographs could be combined into pairs of stereo stills. Other camera booms were located at the port side, stern, and top of the submersible, including one known as the "karate boom" which was swung high above the vehicle, as well as forward and aft to obtain overview images. Fixed, downward-looking black-and-white video and still cameras were mounted to the frame on the starboard side and another video and still camera combination was mounted on the port side boom. These were located in front of the submersible for overhead survey photography and to provide images of the bottom during a landing, to photograph specimens, and to view contents of storage compartments. All of the video

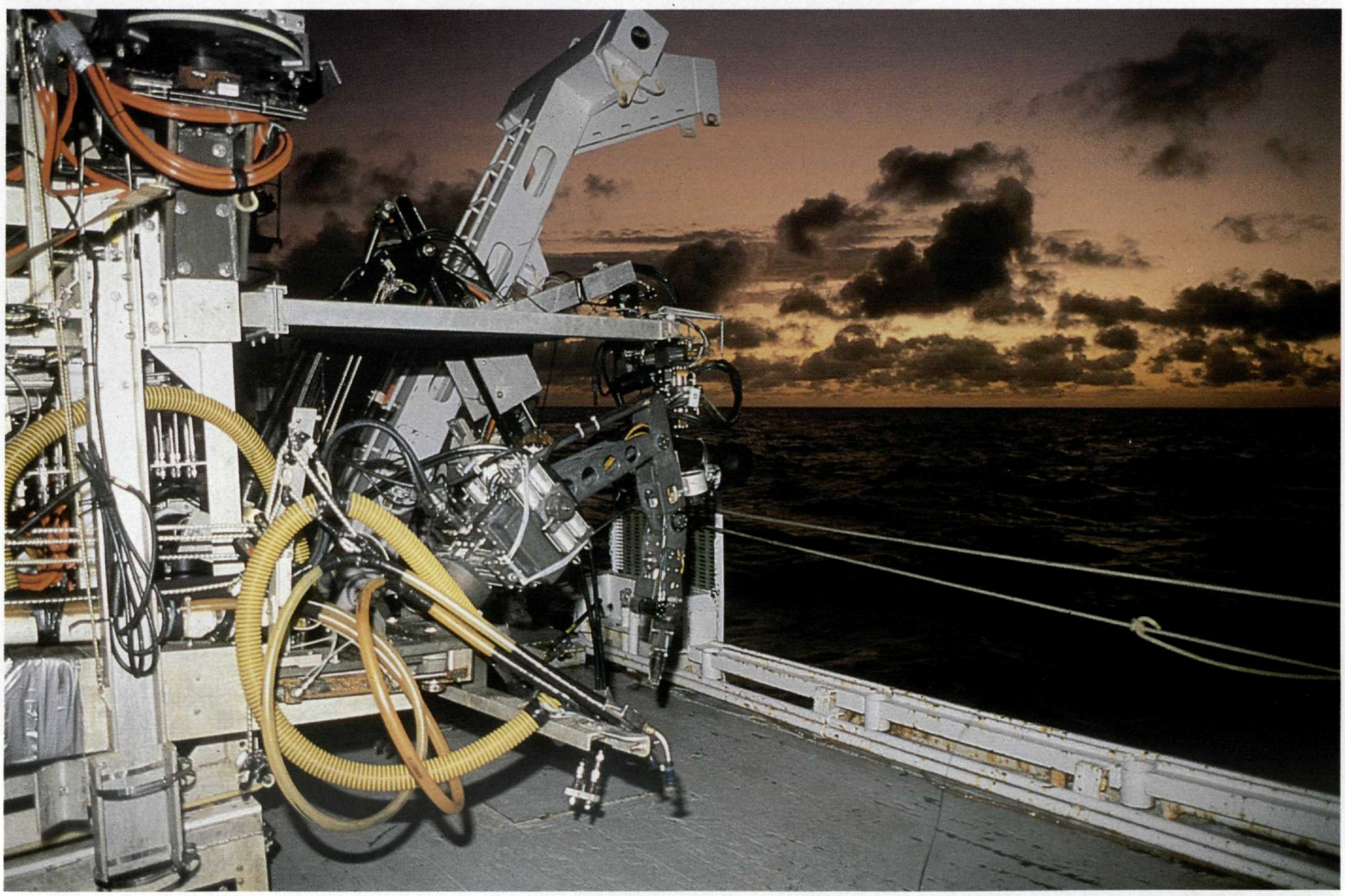


FIGURE 44. Submersible on board the R/V *Arctic Discoverer.* Specialized sampling and observation equipment have been installed on *Nemo* and the vehicle is ready to dive to the shipwreck 2,200 m below. The submersible is a tele-directed robot; can be either controlled by operators using the craft's cameras as underwater eyes or programmed in advance to perform routine functions. About the same dimensions as a mini-van and weighing 6,000 kg, *Nemo* has many special features such as maneuvering thrusters, robotic manipulators, hydraulic storage compartments, specialized collecting tools, powerful lights, and 13 still and video cameras (some of which can produce stereo images).

FIGURE 45. *Nemo* collects a deep-ocean sponge. The manipulator of the remotely operated submersible collects a hexactinellid sponge (*Farrea* new species) from deteriorated ship timbers (top center). The plastic collection container is sitting on coarse pteropod ooze onto which iron corrosion scale and wood fragments from the shipwreck have fallen. The ship's anchor chain can be seen at the upper right.

cameras, as well as one of the 35-mm cameras, were adjustable (focus, zoom, and gain) from the control room on board the research ship.

Lighting of the seafloor was accomplished by various types of underwater lamps or combinations of lamps, depending on illumination requirements. Thallium iodide lamps (250 watts, 4,000 minimum centerbeam candlepower) were used for relatively high overviews where maximum light penetration was required. The greenish illumination of these lamps worked best for black-and-white images. These lamps were pointed downward from retractable "whisker booms" mounted

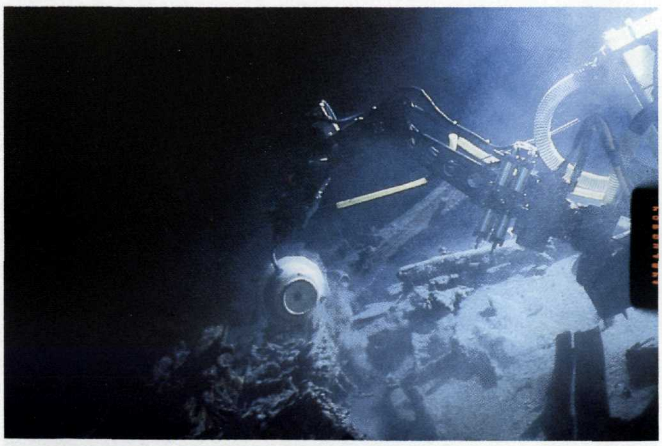


FIGURE 46. *Nemo* collects a shipwreck artifact. A suction-cup picker operated from a manipulator on the submersible recovers a wash basin from the *Central America* (Artifact No. 29001). The wash basin is the type that was probably supplied to the cabins on board the ship. The jumbled, decaying timbers of the ship can be seen in the background.

on the sides of the vehicle. Metal halide lamps (250 watts, 2,800 minimum centerbeam candlepower) yielded a cool white illumination that worked best for color video and close-up investigations of the seafloor. Incandescent lamps were generally used in combination with the metal halide lamps to produce a warmer or more natural-looking image. The latter two types of lamps were mounted on the same controllable booms which held cameras. The main manipulator was mounted on a trolley which permitted the arm and a strobe light source to be extended to about 3 m in front of the vehicle. For still photographs, four strobe lights with pan-and-tilt capability were mounted on the camera booms.

Video images of the site were received "live" in the control room of the *Arctic Discoverer* or recorded at the ocean floor on board *Nemo*. In 1988 and 1989, a video recorder was mounted in a water-tight housing on the submersible. This recorder provided very clear images but only permitted 30 minutes of video recording for each dive. The remainder of the dive was recorded in the control room from images received via coaxial cable. In 1990 and 1991, up to six channels of high-quality video images were transmitted from the seafloor via a fiber-optic cable to the research ship. In the control room, real-time displays were available on 17 monitors, while up to six video recorders were used to store the images. All of the dives for the five-year study were recorded in their entirety in this manner, including a record-long dive of 80 hours in September 1991.

FIGURE 47. *Nemo* collects gold artifacts from the shipwreck. A seabed vacuuming device, "Sea-Vac," operated from the submersible is used to collect gold coins from the *Central America*. Artifact collection trays can be seen at the upper right, each is 40 cm long by 28 cm wide. An extended holothurian (*Chiridota* new species) is visible at the lower left and a brittle star (*Ophiomusium lymani*) at the lower center edge of the photograph.

Two of the video cameras on *Nemo* were mounted side-by-side to serve as a pair of "eyes" for the operators. The signals from this pair of cameras were transmitted to the control room on separate channels through optic fibers incorporated into the cable. In the control room, computers were used to combine the signals and display the resulting images on a special optically-polarized monitor. Each image was displayed with its axis of

FIGURE 48. Gold specie bars and a "tower" of gold coins on the shipwreck. A male brisingid sea star (*Brisinga cricophora*) is positioned on the top of a tower of some 300 gold coins and a 6-armed sea star (*Ampheraster alaminos*) rests on coins and the collapsed timbers of the *Central America*. The container that once held the coins has disintegrated but the coins are left as they were originally stacked.

polarization perpendicular to the other. Thus, when the operators viewed the images using special polarized glasses, the scene on the seafloor was seen in three dimensions.

Video image information from the shipwreck, supplemented by audio comment, was stored on videotape. A separate stereo-image library was created for analyzing detailed portions of the shipwreck. All video images

FIGURE 49. Recovering the tower of coins. The stack of coins shown in Fig. 48 is recovered by first placing an aluminum mold over the tower.

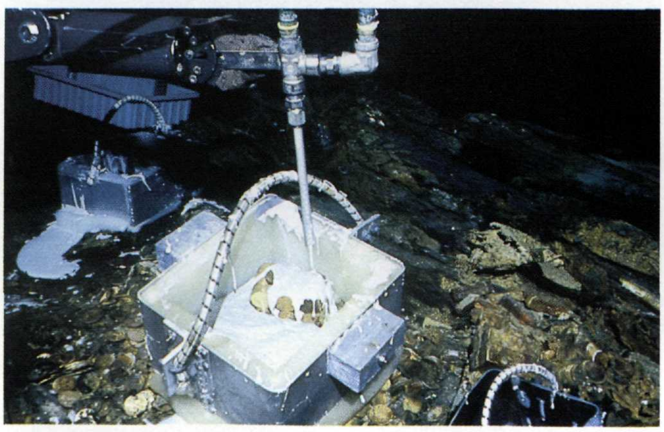


FIGURE 50. Injecting mold with silicone. The mold covering the stack of coins shown in Fig. 49 is injected with a fluid silicone compound that solidifies in several hours. The resulting block can then be recovered without disrupting the arrangement of the coins in the stack.

FIGURE 51. Recovered block of silicone containing gold coins. Approximately 300 gold coins were recovered from the SS *Central America* encased in this block of silicone (see Figs. 48 through 50). The solidified gel resembles a dense foam-rubber that can be easily peeled away from the coins. The coins are uncirculated, $20 double eagles. The mark "1857-S" indicates that they were minted in San Francisco in 1857. The brisingid sea star positioned on the coin tower (see Figs. 48, 49) was also recovered by this process.

combined with still photographs formed a complete record of site exploration, documentation, and excavation tasks. These images also constitute an *in-situ* archaeological record, as well as documentation of environmental and other scientific observations.

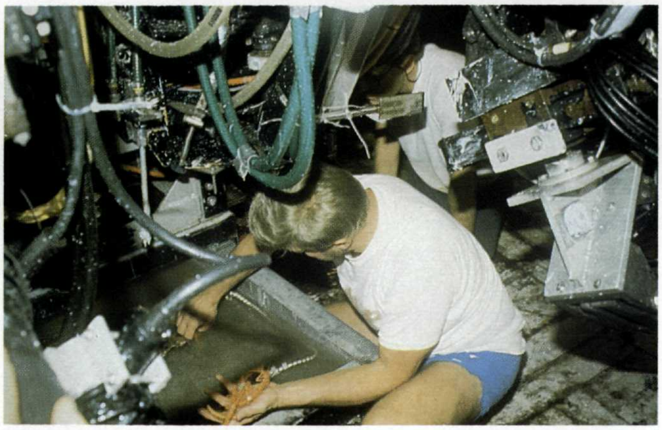


FIGURE 52. *Nemo*'s storage compartment. A brisingid sea star being removed from the specimen storage compartment at the front of the submersible *Nemo*. Note that the sea star has cast off many of its 11 arms during the two-hour ascent to the ocean's surface.

FIGURE 53. The control room on board the *Arctic Discoverer* served as the operations center for the exploration and recovery dives of *Nemo*. Nestled below the ship's pilothouse, the control room crew normally consisted of five people: pilot, co-pilot, navigator, videographer, and mission coordinator. The coordinator planned the dive, oversaw its execution, logged recovered objects, and made scientific observations. Additionally, each crew member had a computer for recording dive information. All of the equipment in the control room was designed to control *Nemo* and receive data transmitted from the ocean floor; 17 monitors and six videotape recorders were used to document each dive. For many routine tasks, *Nemo*'s pilot operated the submersible with a single handle that controlled 15 functions (shown here at right center).

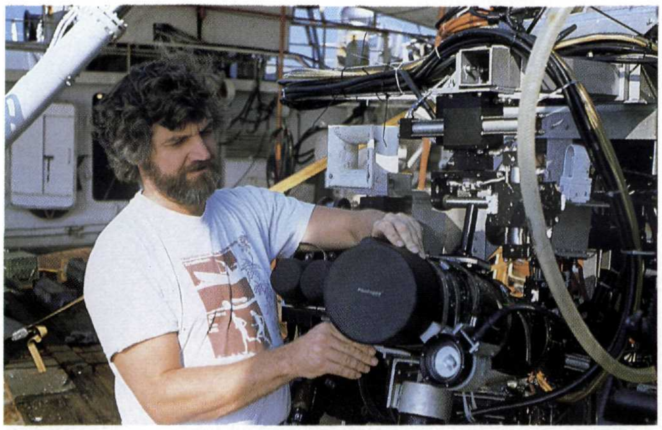


FIGURE 54. Preparing *Nemo*'s cameras for a deep-ocean dive. Milt Butterworth, videographer, adjusts one of *Nemo*'s video cameras.

Oceanographic Methods

An analysis of previously collected oceanographic data from the vicinity of the shipwreck was undertaken to characterize the physical and chemical nature of the ocean at the study site. Data for this analysis was obtained by conducting a search of the electronic files at the National Oceanographic Data Center (NODC) in Washington, DC. The initial search specified all oceanographic data collected within a 2° square surrounding the shipwreck (latitude 30° – 32° N and longitude 76° – 78° W). This search yielded a total of 167 stations but a number were in water shallower than 1,000 m and were deemed unsuitable for the analysis. The search was refined to include only those stations within 1° of the shipwreck site (approximately 100 km) and with depths greater than 1,500 m. This search yielded a total of 71 stations which were then used to characterize the oceanographic nature of the North Atlantic Ocean in the vicinity of the shipwreck. Of these, 28 stations included vertical profile data to the approximate depth of the shipwreck and were used to define the conditions near the seabed at the study site.

The NODC station data consisted of vertical profile measurements (generally 100 m intervals) for the following parameters: depth, temperature, salinity, density (sigma-t), dissolved oxygen, inorganic phosphate (PO_4), nitrates (NO_3), silicates (SiO_3), and pH. The measurements were made from United States and Soviet Union research vessels during the period 1947 to 1981. NODC data is supplied in the following units which are also used in the present paper. Depth is given in meters (m), temperature in degrees centigrade (° C), and salinity in parts per thousand (‰). The density of seawater is expressed in terms of sigma-t (σ_t, a conveniently abbreviated value which refers to the density at standard atmospheric pressure and at the temperature and salinity at which the sample was collected in cgs units minus 1 and times 1,000). A typical density at the site of 1.02786 g/cm^3 would be expressed as 27.86 σ_t. Pure water at 4° C has a 0.00 σ_t; salt increases the density so that seawater at 35‰ salinity and 4° C is 28.00 σ_t. Sound velocity is given in meters per second (m/s) as calculated by the method developed by Wilson (1960). Dissolved oxygen is reported in milliliters per liter (ml/l) and inorganic phosphate, nitrates, and silicates in microgram-atoms per liter (μg-atoms/l) of P, N, and Si, respectively. The percentage of oxygen saturation in relation to temperature and salinity was determined from the table of oxygen solubility in seawater prepared by Grasshoff (1976). Hydrogen ion (H^+) concentration is expressed in pH units. Surface, bottom, and profile conditions were analyzed by pooling data and determining range, mean, and standard deviation where appropriate.

Oceanographic measurements were made at the shipwreck site during most dives. The parameters included: water depth, temperature, current speed and direction, visibility, and turbidity. These data were electronically logged as were supplemental observations made by control room personnel. Voice logs of all crew members and observers in the control room were recorded on the two audio tracks available on the videotape that was simultaneously recording bottom images. Visiting scientists were encouraged to voice their observations regarding the images displayed on the monitors.

Geologic and other seabed samples (i.e., sediment ooze, coal, and wood debris) were collected with an orange-peel sampler or a dustpan sampler. Such samples were either placed in a container or put directly into one of *Nemo*'s storage compartments. In September 1989, a 50-cm sediment core was obtained from a mixed foraminiferal/pteropod ooze adjacent to the shipwreck. Using *Nemo*'s manipulator, a 7-cm diameter PVC core barrel was inserted into the bottom with ease. A check valve at the top of the barrel prevented water from entering the barrel and disturbing the core. The core was retained in the corer while *Nemo* returned to the surface and deck of the R/V *Arctic Discoverer* where the core was extruded. Five horizons within the core were selected for radiocarbon dating which was performed by Geochron Laboratories of Cambridge, MA.

Analysis of the video and still images from the shipwreck site was undertaken by specialists in many aspects of oceanography and marine biology. To supplement the video images and still photographs, representative specimens of many of the organisms observed on the wreck were sampled for more detailed laboratory examination. The collection of biological specimens was accomplished by gathering sessile benthic forms with *Nemo*'s manipulator and placing them in a 20-l polystyrene container (Fig. 45) that was then loaded into a storage compartment on the submersible. Perhaps one of the most difficult tasks of the operation was snapping a water-tight lid on the container from a distance of 2 km but encapsulating the specimens was an effective way to transport them across the water-air interface without damage from agitation as the submersible bobbed in and out of the sea during vehicle recovery. Errant benthic animals were collected with baited minnow traps in which the opening had been enlarged to a diameter of 5 cm (Figs. 55, 56). To attract swimming organisms, a 50-kg pyramidal stack of grouper carcasses was deployed within the wreck site, along with several 5-l, shallow trays filled with fish meal, cornmeal, and a mixture of the two meals (Fig. 57).

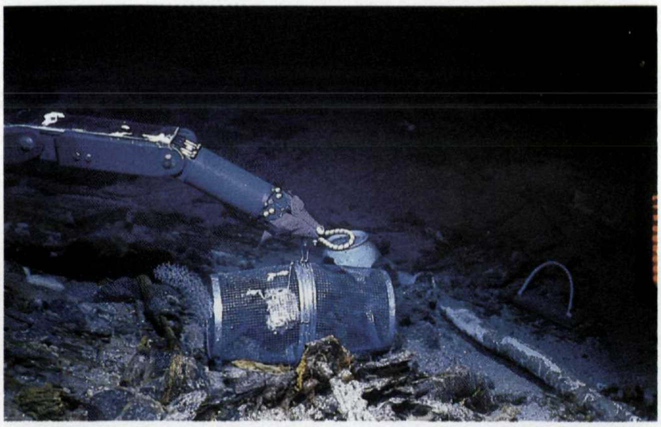


FIGURE 55. *Nemo*'s manipulator is used to retrieve a modified minnow trap that was placed on the shipwreck to collect biological specimens (see Figs. 56, 57, 121).

Appendix A lists the organisms identified from the site, the name and affiliation of the identifier, and whether the identification was made from a photographic image or a specimen. The repository of each specimen and its catalog number are also listed in this appendix. Specific laboratory methods and specialized field procedures used for the various aspects of the investigation are discussed, where applicable, in conjunction with the findings for each subject area.

Archaeological Methods

The SS *Central America* site contained artifacts which reflected a way of life in 1857, not only the construction of nineteenth-century steamships or the habits of their passengers and crew. *Nemo*'s cameras were used to document objects on the seafloor, to establish their relative position within the shipwreck, and to select areas to excavate. Information concerning the artifacts was electronically logged on board the *Arctic Discoverer*. For artifact recovery, *Nemo*'s manipulators were used to grasp artifacts and place them in numbered trays which were then placed inside the submersible's storage compartments. After each dive, the trays were removed from the submersible and taken to a shipboard laboratory where the artifacts were stabilized, cataloged, and stored for further conservation and study at shore-based laboratories. A monitoring program was established to routinely assess the condition of artifacts stored in the laboratories and to initiate preservation actions where warranted.

Thousands of artifacts were documented on the seafloor and a selected assortment of these were sampled. Each type of material that was recovered from the site

FIGURE 56. Five galatheid crabs and two 6-armed sea stars recovered from baited traps set on the shipwreck (see Fig. 55). Four crabs and the sea stars were taken from a trap baited with beef, while one crab (*Munidopsis crassa*) was taken from a trap baited with lobster. The crabs include three *Munidopsis crassa* (white), one *Munidopsis bermudezi* (brown), and one *Munidopsis rostrata* (orange). The two sea stars are the same species, *Ampheraster alaminos*.

FIGURE 57. Bait experiment station. A 50-kg stack of fish carcasses is positioned on the shipwreck (top center) as bait to attract deep-ocean fishes. Four trays (center), two filled with fish meal and two with cornmeal, and two traps (lower center) are also in position at the station. Eelpouts (broad fishes) and blunt-nosed eels (narrow fishes) can be seen feeding at the stations (see Figs. 120, 121).

required an individualized preservation treatment. The comprehensive work edited by Pearson (1987) provides an overview of the problems encountered in marine artifact conservation. For specific materials, the techniques reported in the following works were among the most useful: de la Rie (1992) for ceramics and glass; Cameron (1991), David (1981), Morris and Seifert (1978), and Van Soest et al. (1984) for leather; Horie and Vint (1982), MacLeod (1981, 1982, 1987, 1991), MacLeod and North (1979), Merk (1978), North (1987), North and MacLeod (1987), North and Pearson (1978), Scott (1983), Walker (1982), and Waller (1980) for metals; Bengtsson (1975), de la Rie (1988), Grosso (1975), Koesterer and Geating (1976), Ryder (1984), and Ryder and Gabra-Sanders (1985) for textiles and paper; Grattan (1982, 1987, 1989), Grattan and Clarke (1987), Grattan and McCawley (1978), Grattan et al. (1980), Irwin and Wessen (1976), McCawley (1977), and Rosenquist (1975) for wood; and Selwyn et al. (1993) for wood-metal composites.

The hierarchical nomenclature system presented by Blackaby and Greeno (1988) for man-made objects was used to catalog the artifacts recovered from the site. A brief description of the artifacts is presented in Appendix C; artifact numbers used in the text of this paper refer to objects listed in this appendix.

PHYSICAL SCIENCE

SITE DESCRIPTION

The shipwreck of the SS *Central America* was discovered on a major submarine topographic feature known as the Blake-Bahama Outer Ridge (Fig. 58). This feature is 500 km in length and is composed of sediment 8,500 m thick, making it the largest sedimentary ridge known in the ocean (Markl and Bryan 1983). The location of the shipwreck (approximately 32° N, 77° W) is about 370 km east of Savannah, GA, and 440 km south of Cape Hatteras, NC, but the closest landfall is 270 km at Cape Fear. The wreckage rested at a depth of 2,200 m on a gentle slope of the ridge near to where the ridge merged with a subsided portion of the continental shelf known as the Blake Plateau. The ridge is gently flushed by the Deep Western Boundary Current and the sites were relatively tranquil as evidenced by plant debris and undisturbed animal tracks in the sediment ooze (Fig. 59).

The sediment surrounding the shipwreck was primarily a foraminiferal ooze with a moderate percentage of pteropods (Table 8). Within the hull area of the wreck, the percentage of pteropod shells increased markedly (Table 9). The wreck, which at places rose 5 to 7 m above the bottom, had apparently constricted the bottom

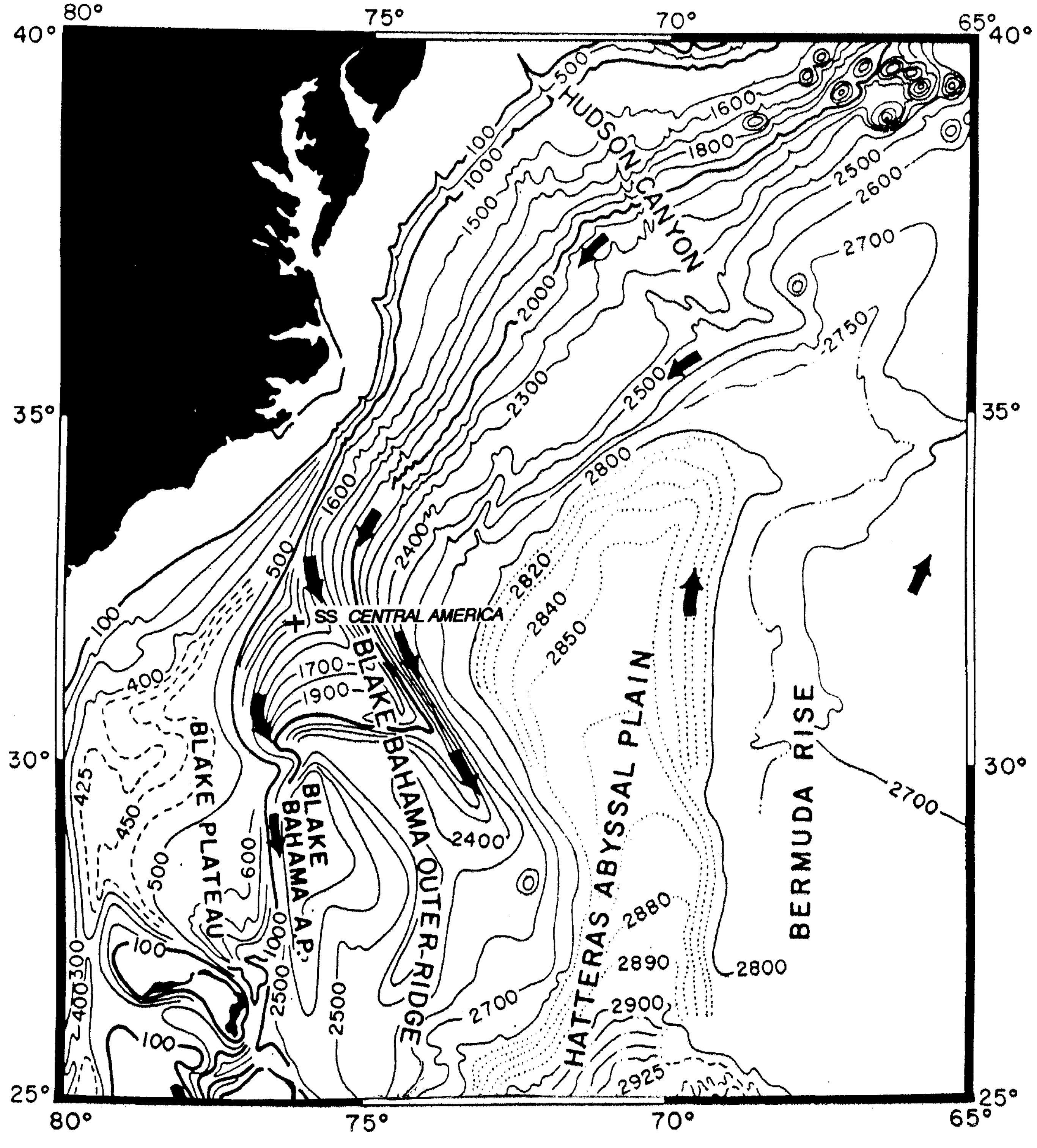


FIGURE 58. Bottom topography of the western North Atlantic Ocean, showing physiographic features and location of SS *Central America* shipwreck. Base map after Schneider and Heezen (1966). Arrows show direction of deep-sea currents. Depth contours are given in fathoms (100 fathoms = 183 m). A.P. denotes abyssal plain.

currents causing an acceleration which had either winnowed out some of the foraminiferans, leaving the larger pteropods behind as a lag deposit, or created an energy shadow within the hull where the suspended pteropods had settled to the bottom adjacent to obstructions. In June 1991, Dr. Paul R. Dando, Marine Biological Association, Plymouth, England, proposed the alternative notion that the high concentration of pteropod shells in the hull area of the shipwreck was the result of the initial impact of the ship on the ocean floor. He suggested that when the ship collided with the bottom, the pteropod shells were more easily mobilized forming a cloud of material which resettled within the wreck, thus accounting for the nearly 1 m thickness of ooze measured

FIGURE 59. Seabed at Site H. The presence of animal tracks in the foraminiferal ooze sediment indicates that the ocean floor in the vicinity of Site H is relatively tranquil. The furrows are probably excavated by enteropneusts and echinoderms. The tubular glass sponges, which cast distinct shadows, are probably *Euplectella jovis.*

in some depressions within the hull area. However, direct observation of a benthic storm at the site in October 1991, showed that such events can also mobilize significant quantities of bottom material.

TABLE 8

Relative abundance of shells in foraminiferal ooze outside the hull area of the SS Central America.

	No. Counted	Abundance (%)
Pteropods and Allies		
Limacina spp.	60	47.64
Creseis acicula	34	26.99
Styliola subula	20	15.88
Atlanta peroni (heteropod)	4	3.17
Cuvierina columnella	2	1.58
Cavolinia uncinata	1	0.79
Cavolinia gibbosa	1	0.79
Clio pyramidata	1	0.79
Diacria trispinosa	1	0.79
Diacria quadridentata	1	0.79
Creseis virgula	1	0.79
Total	126	100.00%
Foraminifera		
Globigerinoid forams	2,000	96.90
Ammodiscoid forams	64	3.10
Total	2,064	100.00%
Shell Fragments and Debris		
Fragments (>200 mesh)	496	100.00%
Summary		
Pteropods and allies	126	4.70%
Foraminifera	2,064	76.80%
Fragments (mostly pteropod shells)	496	18.50%
Total	2,686	100.00%

TABLE 9

Relative abundance of shells in pteropod ooze within the hull area of the SS Central America.

	No. Counted	Abundance (%)
Pteropods and Allies		
Creseis acicula	1,870	53.30
Styliola subula	561	16.00
Limacina spp.	527	15.00
Cavolinia uncinata	161	4.57
Atlanta peroni (heteropod)	84	2.40
Cuvierina columnella	61	1.79
Cavolinia gibbosa	55	1.57
Cavolinia inflexa	54	1.54
Clio pyramidata	45	1.32
Hyalocylis striata	34	0.97
Diacria trispinosa	19	0.54
Creseis virgula	17	0.48
Cavolinia longirostris	11	0.31
Cavolinia tridentata	3	0.09
Carinaria lamarcki (heteropod)	2	0.06
Clio recurva	1	0.03
Janthina exigua (janthinid)	1	0.03
Total	3,506	100.00%
Foraminifera		
Globigerinoid forams	4,828	87.70
Ammodiscoid forams	680	12.30
Total	5,508	100.00%
Shell Fragments and Debris		
Fragments (>200 mesh)	6,120	100.00%
Summary		
Pteropods and allies	3,506	23.20%
Foraminifera	5,508	36.40%
Fragments (mostly pteropod shells)	6,120	40.40%
Total	15,134	100.00%

The shipwreck and primary debris field covered an area of approximately 4 ha. Modeling of the sinking dynamics of the SS *Central America* yielded an estimated descent time of 18 minutes from the time the vessel sank below the surface until it collided with the ocean floor. The velocity on impact was estimated at 7.3 km/hr. The ship appeared to have hit bow first (canted somewhat to the port side) striking with enough force to embed the hull into the sediment ooze along the port side about a meter or two (Fig. 60). The bow had splayed open. The most diagnostic features of the shipwreck were the 10-m diameter iron paddle wheels. The starboard wheel had fallen outwardly and was lying nearly flat on the sediment while the port wheel was bent but still standing at a high angle projecting some 5 to 7 m above the bottom (Fig. 61). Between the wheels, the main components of the engineworks were readily recognized. Ten cubical tanks, about 2 m on a side and believed to be potable water containers, were another distinguishable feature in the wreckage (Fig. 62). The

FIGURE 60. Port hull of the SS *Central America*. Decaying timbers of the shipwreck are colonized by numerous deep-sea invertebrates. From left to right: purple sea cucumbers (*Chiridota* new species) at left top, soft coral (*Neospongodes agassizi*) at center, brisingid sea star (*Brisinga cricophora*) at top center, sea anemone (*Chondrophellia coronata*) at right top, and hydrozoans center and right bottom. Pteropod shells and pholadid bivalve tubes can be seen in the sediment ooze. The port hull of the ship forms a sharp angle as it extends into the ooze at the left side of the photograph. Copper sheathing still covers this portion of the hull, protecting it from wood-borers.

hull had largely collapsed outwardly and the decks appeared to be stacked one on top of the other. The most recognizable wooden structures were the deck (hanging) knees, many of which were still standing upright around the periphery of the after sections of the ship (Fig. 63). The boilers were found displaced in the wreckage suggesting that they may have floated free during the descent (Fig. 64). Scattered within and outside the hull area were massive piles of coal, perhaps 500 tons, with most lumps in the 10 to 20-cm size range (Fig. 65). Much of the gold treasure formed discrete deposits on the shipwreck site, where ingots were strewn over collapsed decks and coins were perched on decaying beams (Fig. 66), while other bars and coins had fallen through openings formed as the ship collapsed.

The wooden timbers were highly degraded, having been riddled by wood-boring bivalves (Figs. 67, 68). Their tunnels ranged in diameter from less than 0.5 cm to nearly 2 cm. The calcareous linings or tubes formed by these molluscs were much in evidence in the wood and on the seabed where they had fallen from disintegrated timbers. Copper sheathing, which once covered portions of the hull and rudder (Fig. 69) below the waterline, was also a noteworthy element of the shipwreck.

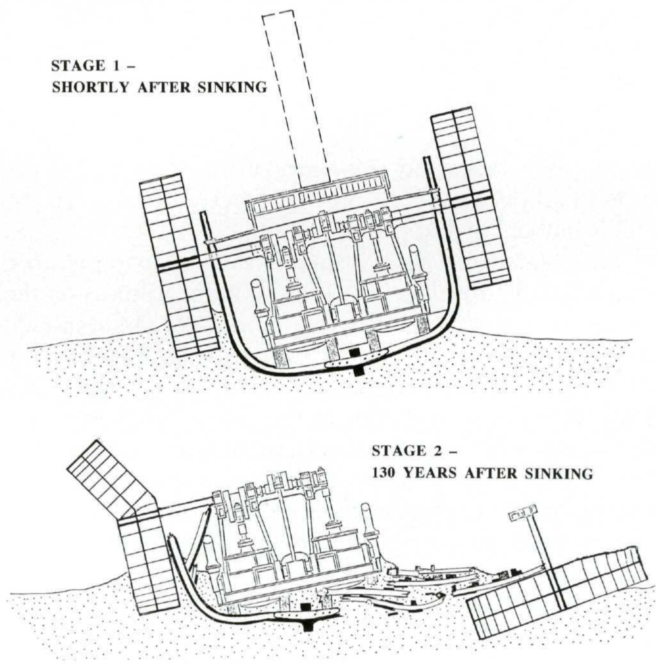


FIGURE 61. Stages in the degradation of a nineteenth-century, wooden-hulled, side-wheeled, steamship sunk in the deep ocean. The SS *Central America* is believed to have undergone this type of transformation in the 130 years since its sinking.

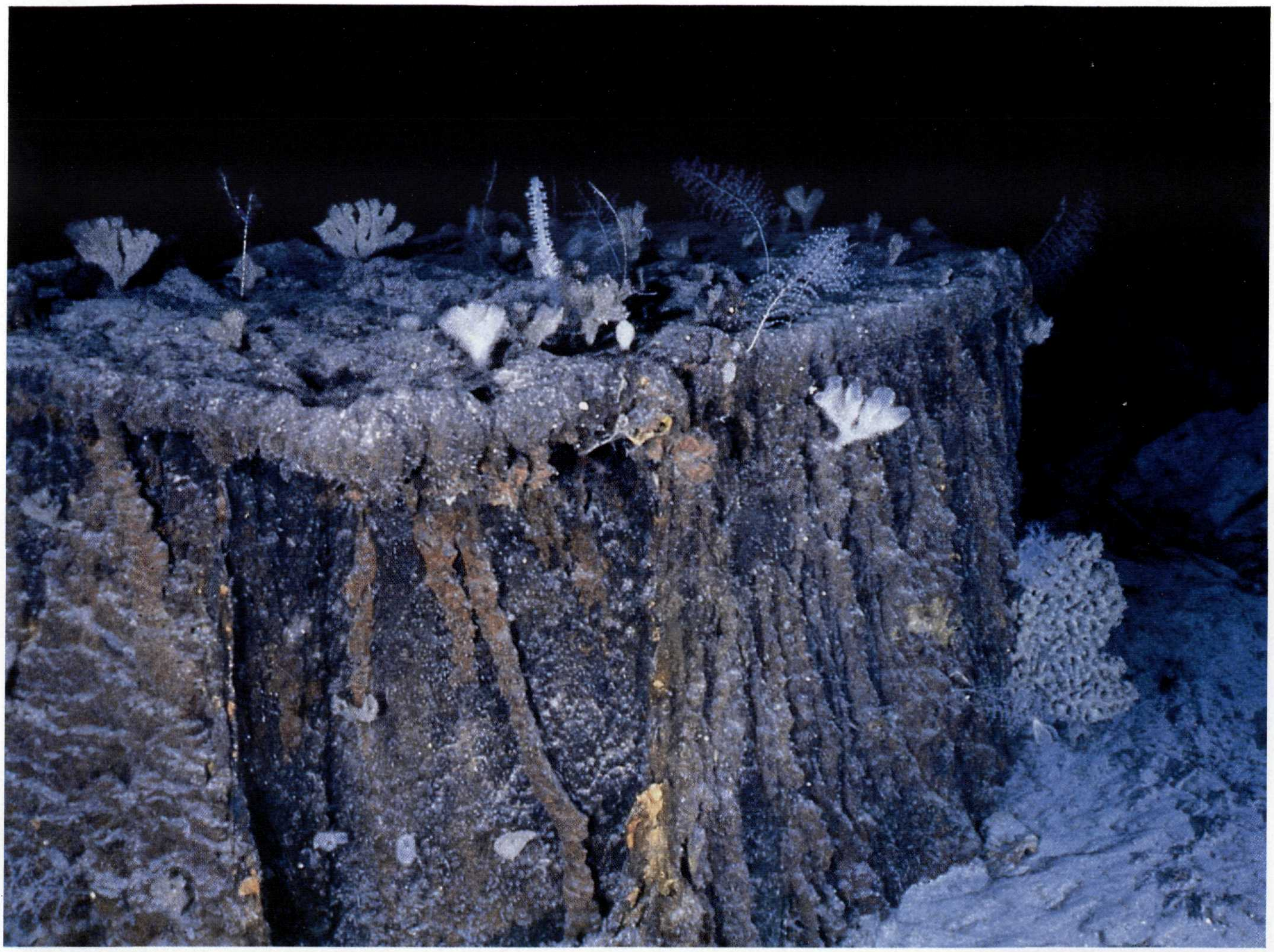


FIGURE 62. Iron tank on the shipwreck of the SS *Central America.* On the perimeter of the collapsed hull, about ten cubical structures rest on the seafloor. Each is about 2 m on a side and constructed of wrought iron plates joined together with riveted bars of angle iron; the ship's anchor chain is draped across the top of one of them. They were probably used to hold fresh water for the passengers and crew. The tanks hold an estimated 6,500 l of water—the equivalent of about 11 l of drinking, cooking, and washing water per day for each person on board during the nine-day cruise from Panama to New York City. The sides of the tanks are distorted with ribbons of iron rust formations and the tops are heavily colonized by glass sponges and gorgonian corals.

At places it indicated the form of the ship where the wood had decayed and in other places it preserved the ship's timbers by copper poisoning.

Rust stalactites and iron-corrosion flow-structures, referred to as "rusticles," were prominent features on the ironworks of the SS *Central America.* On exposed surfaces, such as the anchor chain (Fig. 70) and the under-side of iron members, rusticles up to 30 cm long were noticeably bent in the same direction as the dominant, southwesterly-trending bottom current (Fig. 71). Video images showed that gorgonian corals attached to the upper surface of the side wheel were also bent in the same direction as the relatively uniform 10 cm/s current.

The debris field surrounding the hull was littered with pieces of the ship and articles once belonging to the passengers and crew. Of special interest were a number of leather-bound trunks (Fig. 72) that had survived in remarkably good condition (see Underwater Archaeology section later in this paper).

PHYSICAL AND CHEMICAL OCEANOGRAPHY

The mass of surface water off the eastern coast of North America, including the Gulf Stream and the Sargasso Sea, is termed Western North Atlantic Water. Surface circulation of the North Atlantic Ocean consists of a large clockwise spiral or gyre. Because of the earth's easterly rotation, moving water masses are deflected to the right in the Northern Hemisphere (Coriolis effect) which tends to concentrate strong surface currents on the western side of the ocean basin through a process known as westward intensification (Thurman 1991). Such currents, e.g., the Gulf Stream, are known as western boundary currents. Surface currents, however, do not represent the total circulation of water in the Atlantic. Deep-ocean water undergoes both vertical and horizontal movement driven by differences in temperature and salinity (thermohaline circulation). Deep-water masses originate at the ocean's surface in sub-polar regions, sink, and flow toward lower latitudes. Ocean-bottom currents generally follow the same deflection pattern as the surface

FIGURE 63. A hanging knee, which once braced a deck to the hull of the *Central America*, now serves as a perch for an orange brisingid sea star (*Brisinga cricophora*), feathery golden corals (*Chrysogorgia* new species), reddish-purple soft corals (*Anthomastus agassizi*), and a sea anemone (*Chondropellia coronata*). The knee is riddled with holes created by wood-boring bivalves (*Xyloredo* spp.).

FIGURE 64. Corroding ironworks, probably small boilers or tanks, on the shipwreck. These structures form an ideal habitat for sponges, corals, and crinoids. The "Y-shape" glass sponges are members of the genus *Rhabdodictym*. In the right foreground, a feather star crinoid (*Caryometra alope*) is attached to the axial stalk of a gorgonian coral, *Chrysogorgia* new species. In the center background, a stalked crinoid (*Porphyrocrinus* sp.) is growing attached to the side of a boiler. A horizontal plume of the hexactinellid sponge *Farrea* new species can be seen to the left of this crinoid. Mounds of coarse pteropods partially bury the boiler. In the center and left of the photograph, decaying timbers lie on the ocean floor and a piece of copper sheathing projects diagonally upward at the far left.

currents but they are slower and strongly influenced by the bottom terrain.

Several thermal layers comprise Western North Atlantic

FIGURE 65. The tons of boiler coal on the shipwreck site form a solid habitat for benthic animals. Several branching glass sponges (*Rhabdodictym* sp.) can be seen at the top of the photograph and a stalked crinoid (*Porphyrocrinus* sp.) at the bottom center. What appears to be a reddish-purple tethyid nudibranch is perched in the crown of this crinoid. At the right, a brittle star (*Ophiomusium lymani*) is making its way onto the coal pile from the sediment ooze. Numerous tubes from pholadid wood borers are scattered over the lumps of coal.

FIGURE 66. Gold specie bars and coins on degraded timbers of the shipwreck. Due to a low sedimentation rate at the site and the collapsed nature of the ship, the gold treasure is exposed on the seabed. Plumes of the gorgonian coral *Chrysogorgia* new species can be seen attached to the timbers and pieces of gold. Attached to many of the axial rods of the coral are crinoid feather stars (*Caryometra alope*). At the lower right, a large female brisingid sea star (*Brisinga cricophora*) is resting on a tower of 300 gold coins (see Fig. 48). What is believed to be a male of the same species (small, white-colored) is clinging to the coins midway up the tower (partially concealed by the arms of the female). Shortly after this photograph was taken, the female placed her central disc over that of the male—a behavior that may enhance egg fertilization.

Water. The upper one is a diurnally mixed layer governed by insolation heating and wind stirring that generally ranges from 5 to 10 m thick (Emery and Uchupi 1972). Deeper, a seasonally mixed layer may extend to a depth of 100 to 300 m depending on storm intensity. Beneath the zone of seasonal mixing a permanent layer of moderate temperature gradient (thermocline) extends to a depth of about 1,000 m at the western edge of the Sargasso Sea. The bottom of the thermocline approximately coincides with the 4° C isotherm.

As will be discussed later, several deeper water masses underlie Western North Atlantic Water and potentially impacted conditions at the shipwreck site. Mediterranean Water is a high-salinity water mass beneath the Western North Atlantic Water that has been traced from the Straits of Gibraltar westward for over 5,000 km. A tongue of Mediterranean Water reaches at least as far as the Bermuda Rise at the 10° C isotherm where further westward movement is rather complex and involves intrusion into cooler and less saline waters (Katz 1970, Price 1992). Typically, Mediterranean Water is between Western North Atlantic Water and deeper water masses. Mediterranean Water rarely reaches to the seabed but it can mix with and influence deeper water masses.

Gulf Stream

The average volume of water transported by the Gulf Stream through the Straits of Florida is 32 million m^3/s; a downstream increase in volume swells this number to 65 million off Cape Hatteras, NC, and 140 million off Nova Scotia, Canada (a 7% increase for each 100 km along the current's path) (Knauss 1969). By way of comparison, all of the earth's terrestrial streams average only 1 million m^3/s (Holeman 1968). The core of the Gulf Stream, the jet, is about 80 km wide and appears to follow the contour of the continental rise at speeds up to 5 knots (2.6 m/s). As it progresses northward, numerous meanders in its course may swing it as much as 65 km from a straight current path, only to resume its normal course up to 300 km farther downstream. These meanders are unstable, often becoming so curved that they break away as independent cold core eddies that persist for some time in the Sargasso Sea and sometimes in the shelf water as warm core eddies. The mean path of the Gulf Stream off the eastern coast of the United States corresponds approximately with the 200-m-depth contour (Fig. 73). Analysis of the meanderings of the Gulf Stream from its mean path (Fig. 74) shows that the shipwreck of the SS *Central America* is at the outer fringe

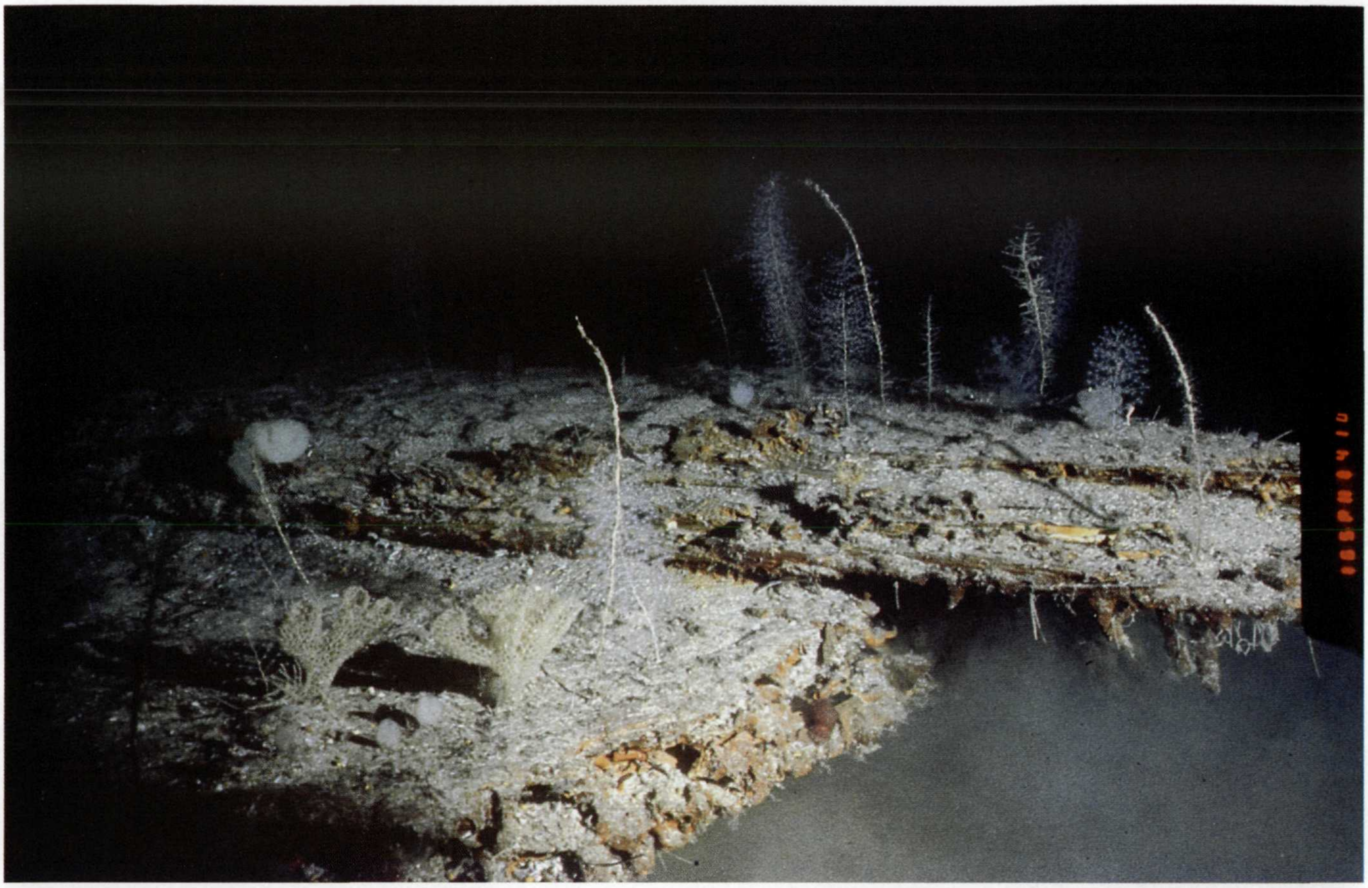


FIGURE 67. Degraded ship timbers provide a hard substrate for the attachment of sessile animals. The branching glass sponges at the lower left are in the genus *Rhabdodictym*, and the plumy gorgonian corals are an undescribed species in the genus *Chrysogorgia*. Numerous atrophied axial rods of this coral can be seen scattered over the upper surfaces of the deck. The timbers (from a light deck or a cabin partition) show signs of wood-borer infestation. Corroded iron spikes can be seen projecting from the underside of the wood.

of the meander envelope (Olson et al. 1983), thus the Gulf Stream is positioned over the shipwreck only a small percentage of the time. Historical evidence (see History section earlier in this paper) indicated that, at the time of the sinking, the SS *Central America* was indeed in the Gulf Stream and that this current was experiencing an extreme eastward excursion.

Water temperatures in the Gulf Stream are relatively warm (annual mean of about 26° C on the surface and 10° C at a depth of 800 m) because most of its water comes from tropical regions (Groves and Hunt 1980). Inshore surface waters are generally 5° colder than the Gulf Stream, whereas east of the Stream, in the Sargasso Sea, they are about the same as in the Gulf Stream. As R/V *Arctic Discoverer* traversed the ocean from the shore to the shipwreck site, a sharp boundary was often noted where the turbid inshore water met the clear, deep-blue water of the Gulf Stream. However, the boundary between the Gulf Stream and the Sargasso Sea was discernible only by the absence of strong currents in the latter. The position of the R/V *Arctic Discoverer* above the shipwreck was often at or near the interface of the Gulf Stream and the Sargasso Sea.

Sargasso Sea

A sea without a coast, the Sargasso Sea is the calm center of the North Atlantic Ocean gyre and covers an area of 5.2 million km^2 (Groves and Hunt 1980). Water circulation is clockwise (anticyclonic) around the edges of the Sea forming the gyre, which is skewed to the western side of the North Atlantic—primarily the result of the Earth's rotation (Coriolis effect). This asymmetry results in a narrow, strong current on the western flank (i.e., Gulf Stream) and a broad, gentle current on the

FIGURE 68. Recovered timber from the shipwreck. Shipwreck timbers had been heavily infested with pholadid wood borers. This piece of recovered wood is riddled with borer tunnels and the remains of calcareous tubes. Photograph courtesy of Dr. Ronald B. Toll.

FIGURE 69. Copper sheathing that once covered a hinged, wooden rudder. The wood has since decayed. The sheathing is now colonized by an 11-armed brisingid starfish (*Brisinga cricophora*), a 6-armed, pedicellasterid starfish (*Ampheraster alaminos*), dozens of sessile barnacles (*Verruca* sp.), and numerous hydrozoan colonies. An ophidiid fish (*Barathrodemus manatinus*) swims beneath the sheathing which is partially buried in foraminiferal ooze. The sediment ooze appears to have accumulated in the protected area at the left side of the photograph and to have scoured at the more exposed area on the right side. The hull beneath the waterline on the *Central America* was covered with copper plates to retard shipworm infestation. Recovered sheathing plates (Artifact No. 19007) had an average thickness of 0.6 mm.

FIGURE 70. Anchor chain of the SS *Central America*. The chain is draped over a large water tank and exhibits iron rust formations known as "rusticles." Iron-oxidizing bacteria have mobilized the iron resulting in the stalactite-like features hanging from the undersides of the links, some 25 cm long. The elongated arms of a brisingid sea star (*Brisinga cricophora*) hang between the rusticles and small colonies of hydrozoans and hexactinellid sponges can also be seen.

FIGURE 71. Iron beam on the shipwreck colonized by gorgonian corals, hexactinellid sponges, and hydrozoans. The rust features (rusticles) projecting downward from the structure are facilitated in their growth by iron-oxidizing bacteria (*Leptothrix*). The deflection of the rusticles toward the right (southwest) demonstrates a long-term current movement in that direction (southward-flowing Deep Western Boundary Current), while the bending of the coral indicates a short-term flow in the same direction. Typical current velocities are about 10 cm/s.

FIGURE 72. Leather-bound steamer trunk on the seabed near the shipwreck of the *Central America*. The trunk (see Fig. 95) is colonized by large sea anemones (*Paractinostola* new species ?) and a plumy golden coral (*Chrysogorgia* new species).

eastern flank (i.e., Canary Current). The northern segment of the gyre is termed the North Atlantic Drift and the southern is known as the North Equatorial Current.

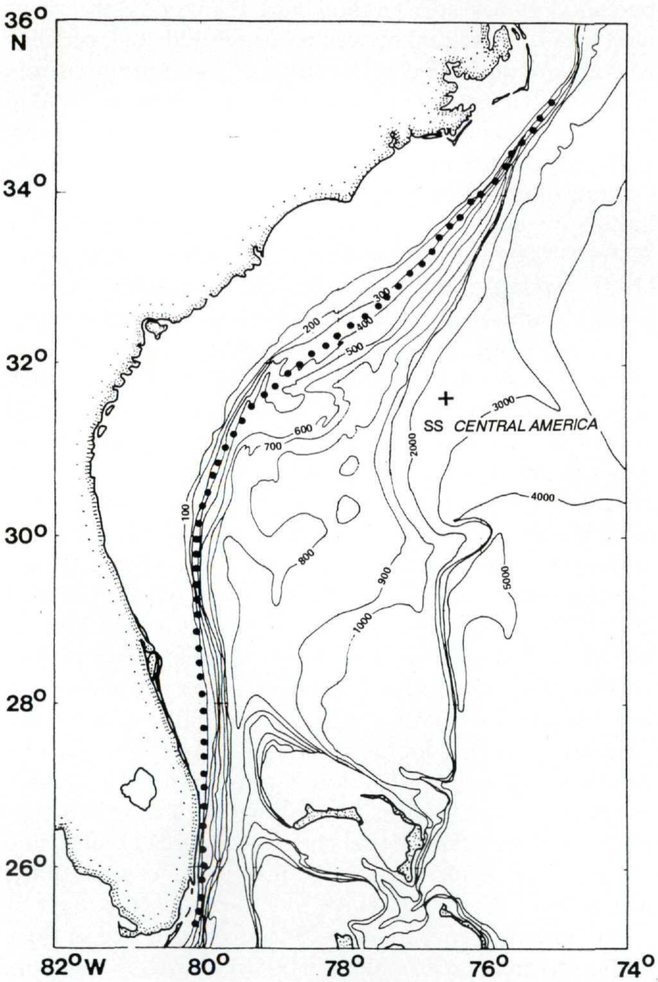


FIGURE 73. Average position of the Gulf Stream plotted over the bathymetry of the South Atlantic Bight, showing location of the SS *Central America* shipwreck. Depth contours are given in meters. Base map after Olson et al. (1983).

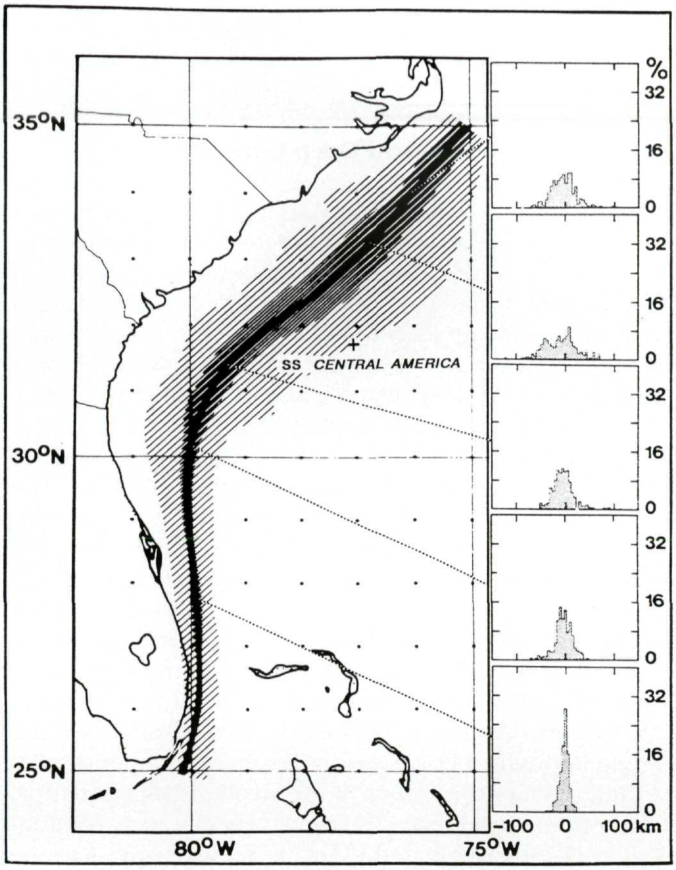


FIGURE 74. Statistical plot (mean, standard deviation, and total range) of Gulf Stream paths between 25° N and 35° N, showing location of SS *Central America* shipwreck. Base map after Olson et al. (1983). Frequency of occurrence histograms of cross-stream displacement (east-west) for the surface front are plotted along the right-hand side of the figure for selected places along the mean path. Note how the distribution spreads to the east in the vicinity of the shipwreck.

The Sargasso Sea is hydrodynamically a "storehouse" of potential energy. This energy (3×10^9 ergs/cm) is built up by action of the planetary wind systems which pile the warmer, less dense, surface water into a mound that floats hydrostatically on the colder water beneath (Stommel 1958). The rise is about 1 m in the center of the Sargasso Sea (Von Arx 1962) which stores enough energy to maintain the North Atlantic gyre for 1,700 days in the absence of any additional driving force of the wind.

The mass of warm (annual mean 25° C) saline water making up the Sargasso Sea is fairly deep. The 4° C isotherm is located at a depth of about 1,700 m at the center of the Sargasso Sea (Emery and Uchupi 1972), and tapers to 1,200 m at the shipwreck site near the western edge of the Sea. The salinity is generally above 36.5‰ at the surface, with values ranging from greater than 37‰ in the eastern margins of the Sea to about 36‰ in the western. The arid atmospheric conditions over the Horse Latitudes (30 – 35° N) of the Sargasso Sea, with a predominance of evaporation over precipitation, produce high salinity (Gordon 1966). Biological productivity in the Sargasso Sea is typically low, in large part owing to the permanent thermocline which blocks the upward diffusion of nutrients. The most characteristic plant life in the Sargasso Sea is floating brown algae (*Sargassum* spp.) from which the sea gained its name.

Deep Water Masses and Deep Currents

The western North Atlantic Ocean has multiple sources of deep and bottom waters. Deep water masses are defined as those that flow between the surface or intermediate water masses and the seabed. However, if the deepest water has characteristics distinguishing it from the overlying deep water, it is referred to as bottom water. Bottom water is always in contact with the seabed. The major deep water mass off the east coast of North America is termed North Atlantic Deep Water. This mass comprises about 70% of all the North Atlantic water colder than 4° C (Wright and Worthington 1970). The main source of North Atlantic Deep Water is believed to be cold, oxygen-rich, sub-polar surface waters from the Arctic, with lesser contributions from Antarctic waters and the Mediterranean Sea. Deep-water movements in the North Atlantic are driven by the differing densities of the water masses. The resultant bottom currents tend to follow the contours of the ocean floor. At certain times and places, current velocities on the ocean floor are strong enough to erode and redistribute sediments.

In the deepest portions of the western North Atlantic, the bottom water mass is known as Antarctic Bottom Water. Having originated as a sinking water mass in the Weddell Sea, it enters from the southeast and is characterized by a temperature of 0.5° C, a salinity of 34.8‰ and a flux of 1 to 2 million m^3/s (McCave and Tucholke 1986). At the *Central America* shipwreck, occasionally, tongues of this flow appeared to move up the continental slope and invade the site. When such events occurred, the dominant southerly flow was reversed to a northerly flow and the temperature decreased. Normally, however, the shipwreck was under the influence of North Atlantic Deep Water which originated in the Norwegian Sea, with lesser amounts from the Irminger and Labrador Seas (Tolmazin 1985). These sinking masses join and flow southward as Norwegian Sea Overflow Water. This flow becomes incorporated in North Atlantic Deep Water at the middle latitudes and south of 45° N, it mixes with warm, high-salinity water from the base of the Gulf Stream and with some cold Antarctic water. Along the lower part of the continental slope, North Atlantic Deep Water flows south along the ocean floor but farther offshore, at depths greater than 3,000 m, it rises over the more dense Antarctic Bottom Water which is slowly flowing in a northerly direction (Emery and Uchupi 1972). At the shipwreck site, 2,200 m, North Atlantic Deep Water flow was generally in a southerly direction at 0.2 knots (10 cm/s) and the water mass was characterized by temperatures of 2 to 4° C.

In the region of the Blake Ridge, the Deep Western Boundary Current (also known as Western Boundary Undercurrent) incorporates North Atlantic Deep Water (from the Norwegian Sea) at 2,000 to 3,000 m, as well as Antarctic Bottom Water (from the Weddell Sea) at greater depths. Over the ridge, the current flows strongly southeastward with highest velocities occurring at depths between 3,000 and 4,000 m (mean velocity of 22 cm/s at 3,600 m) (McCave and Tucholke 1986). Moving southward, the current follows the contours of the Blake Ridge, thence along the flank of the Blake Escarpment until it joins the top of the Antarctic Bottom Water at the Bahama Banks. A portion of the normally northward flowing Antarctic Bottom Water is probably entrained in the southerly-flowing Deep Western Boundary Current. Using tritium tracers, Jenkins and Rhines (1980) demonstrated that water from the Norwegian Sea is transported to the Blake Ridge in about 15 years.

Background turbidity values associated with deep waters in the western Atlantic Ocean are a function of the rate of biogenic fall-out from the surface water (Eittreim and Ewing 1974). However, the near-bottom velocities and associated shear of the Deep Western Boundary Current produce high turbidity intensities which decrease exponentially upward for a few hundred meters (Volkmann 1962, Swallow and Worthington 1961). In October 1991, what could aptly be described as a "benthic storm" was observed at the shipwreck site. The current velocity at the site had increased 10-fold from its normal rate to an estimated 100 cm/s. This velocity easily exceeded the critical erosion threshold of 20 cm/s (Gardner and Sullivan 1981) for the foraminiferal and pteropod oozes surrounding and blanketing the shipwreck. As the sediment was resuspended, the visibility was greatly diminished. The force of the bottom current was such that normal recovery strategies at the site had to be modified. This event and several less dramatic current fluctuations appeared to be associated with reversals in current direction resulting from probable invasions of the site by masses of Antarctic water (Antarctic Bottom Water). As similarly observed by Gardner and Sullivan (1981) north of Bermuda, there was no apparent correlation with atmospheric storms and benthic storms at the site.

In the North Atlantic a deep-sea nepheloid layer (zone of increased turbidity) is caused by the resuspension of sediment by strong bottom currents. Ewing and Thorndike (1965) found that elevated suspended particle concentrations occur in benthic nepheloid layers that are associated with the Deep Western Boundary Current off the east coast of North America. They documented consistent concentrations ranging from 50 to 100 μg/l of suspended sediment in these layers, while Gardner and Sullivan (1981) recorded concentrations as high as 400 μg/l during a benthic storm in the same region. Fortunately, the upper boundary of nepheloid layers was found to lie farther offshore and farther down the continental slope (depths >3,000 m) than the SS *Central America* shipwreck. The cloudy conditions of this layer were rarely observed at the shipwreck site which normally exhibited exceptional clarity. This greatly facilitated the ability of *Nemo*'s cameras to image the features of the ocean floor.

By human standards, conditions on the ocean floor at the site are exceedingly harsh. Organisms living there have had to endure low temperatures (2 to 4° C), darkness, and immense pressure. At the ocean's surface, the pressure felt by animals is that of one atmosphere (1 kg/cm^2 or 100 kPa), whereas at the shipwreck depth of 2,200 m, it is 220 atmospheres (220 kg/cm^2 or 22,000 kPa). The impact of this increased pressure was demonstrated by placing several Styrofoam® coffee cups in a mesh bag secured to the submersible before a dive to the shipwreck site. On *Nemo*'s return to the surface, it was noted that all of the air spaces in the cups had collapsed resulting in "thimble-sized" cups. The actual volume loss of an original 220-ml cup was 91%. Such pressure appeared to have no effect on the shape of animals observed on the shipwreck since there were no gas-filled spaces in their bodies. If such were the case, they would have been compressed flat at this depth. Conversely, body fluids have extremely low compressibility so that physically, deep-sea animals can withstand the high pressures. Chemical reactions, however, such as those involved in respiration and digestion are most likely affected by pressure. Very little is known about the effect of pressure on deep-sea organisms and precisely how they cope with it but Somero et al. (1983) showed that elevated pressures, particularly in association with low temperatures, retard enzymatic functions in deep-sea organisms.

In the deep waters of the western North Atlantic Ocean, chemical and physical properties of seawater, with the exception of the properties discussed above (currents and hydrostatic pressure), have relatively narrow ranges at any specific site below the permanent thermocline. Solar radiation has no direct ecological significance because all light, except bioluminescence, disappears at depths below 1,000 m (Gage and Tyler 1991). At 2,000 m, temperatures are below 4° C and salinity is nearly constant at 35‰ (Menzies et al. 1973). Water below the 1,000 m level is about four-fifths saturated with dissolved oxygen for the temperature of the water, except for some minor reductions near the seabed caused by sediment oxygen demands (Bruun 1957).

The high concentration of dissolved oxygen at the site appeared to be maintained by atmospheric exchange with cold surface water (which can dissolve a greater quantity of gas because of its low temperature) in the sub-polar regions, subsequent sinking, and relatively rapid transport (about 300 km/yr) in the deep ocean. Because the deep water was most likely at the surface more recently than the water at intermediate depths (300 to 1,000 m), the bottom water had been less subjected to biological respiration and thus was higher in its oxygen content (Ross 1982).

The water-quality parameters measured at the shipwreck site typically had the following values: depth, 2,200 m; solar radiation, nil; pressure, 220 atm (22,000 kPa); current, 10 cm/s (mean); and visibility, 15 to 20 m. Anticipated values for salinity, 34.8 to 35.1‰; dissolved oxygen, 5 to 6 ml/m; pH, 7.8 to 8.2; and turbidity, ~20 mg/m^3 were interpolated from literature values (Emery and Uchupi 1972, Florian 1987, Horne 1969, McCave and Tucholke 1986) for the bottom waters on the Blake Ridge.

At depths twice as great as the shipwreck, the solubility of calcium carbonate increases under the influences of hydrostatic pressure, temperature, and carbon dioxide concentrations to the point, the lysocline, where calcareous shell material dissolves. Beyond such depths, siliceous shells of radiolarians and diatoms, and lithogentic red clay are the chief components of the sediment. Emery and Uchupi (1972) found that the waters of the North Atlantic Ocean are undersaturated for aragonite below 2,300 m and for calcite below 4,000 to 5,000 m. These are the two chief calcareous minerals in marine shells. They concluded that the depth of compensation (the depth where a marked decrease in the content of calcium carbonate in the sediments occurs) is about 700 m below the depth of saturation. Thus, at a depth of 2,200 m, the sediments associated with the shipwreck had not been significantly leached of their original calcium carbonate content.

NODC Data

Surface Conditions. National Oceanographic Data Center (NODC) data from 71 stations (34-year period; collected for all seasons) were analyzed to characterize surface conditions near the study site. The surface temperature ranged from 20.36° C in February to 28.85 °C in September with an annual mean of 25.24±2.81°C. The surface salinity showed considerably less annual variation, ranging from 35.86 to 36.80‰ with a mean of 36.30±0.17‰. Surface density values reached nearly 26 σ_t in winter and dropped to about 23 σ_t in late summer. Sound velocities in the surface waters also varied seasonally, from about 1,525 m/s in winter to 1,545 m/s in summer. Largely in response to seasonal temperature variations, dissolved oxygen in the surface waters typically fluctuated from 4.4 ml/l (98% saturation) in September to 5.8 ml/l (116% saturation) in February. In July 1966 a maximum value of 6.27 ml/l (139% saturation) was recorded, most likely in response to high phytoplankton productivity. The mean surface oxygen was 5.12±0.48 ml/l and the mean percentage of saturation, in relation to the surface water temperature, was 109±9%. The biological nutrients (phosphates, nitrates, and silicates) were generally low in the surfaces waters but reached their highest concentration in winter. Surface water pH ranged from 8.08 to 8.32 with an annual mean of 8.18±0.11.

Oceanographic Depth Profiles. Figure 75 illustrates nine oceanographic parameters as a function of depth. The profiles for temperature, salinity, density, sound velocity, oxygen, and pH represent typical late summer conditions, the period of the year when most of the scientific observations at the *Central America* shipwreck were undertaken. Deep-profile nutrient measurements were not available for this time of year. Thus, the phosphate, nitrate, and silicate profiles are representative of early spring conditions.

There is consistent agreement among the profiles in that collectively they indicate a distinctive cold, less saline, and oxygen/nutrient-rich water mass below a depth of 1,000 m. The temperature profile illustrates three features: 1) a mixed surface layer, 2) a permanent thermocline below a depth of 300 m that extends down to 1,000 m, and 3) a uniform deep layer. Salinity mirrors temperature and the same pattern is reflected in the density and sound velocity profiles which are strongly influenced by

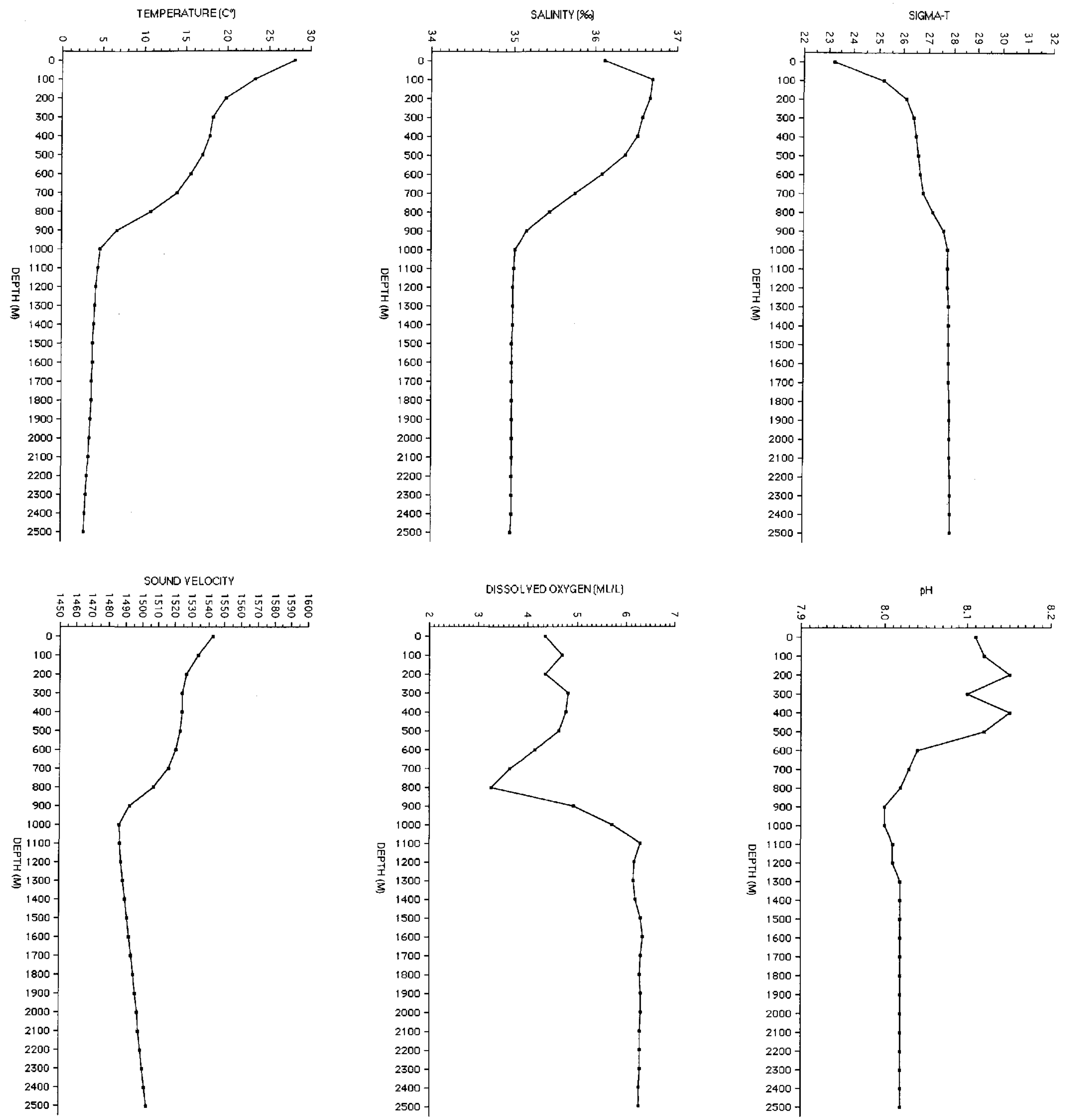


FIGURE 75. (CONTINUED ON NEXT PAGE.)

temperature and salinity. In the sigma-t profile a distinct pycnocline can be seen above the 1,000-m depth that corresponds to the position of the thermocline. The dissolved oxygen profile demonstrates an oxygen minimum at 800 m and a well-oxygenated deep layer. The oxygen minimum layer is discussed below. All of the biological nutrient profiles show a dramatic increase through the thermocline and high, relatively stable, concentrations in the deep layer, with a typical phosphates to nitrates ratio of 1:15. Similar to temperature and salinity, pH decreases through the thermocline and showed a minimum value at 900 m. As with the other parameters pH is comparatively uniform in the deep layer.

Oxygen Minimum. At the ocean surface, seawater is continually saturated, or supersaturated, with oxygen by virtue of agitation at the sea-atmosphere interface and by the liberation of oxygen through algal photosynthesis. Below the euphotic zone, oxygen loss through respiration exceeds that produced by phytoplankton photosynthesis. At greater depths, oxygen continues to be consumed by microbial decomposition

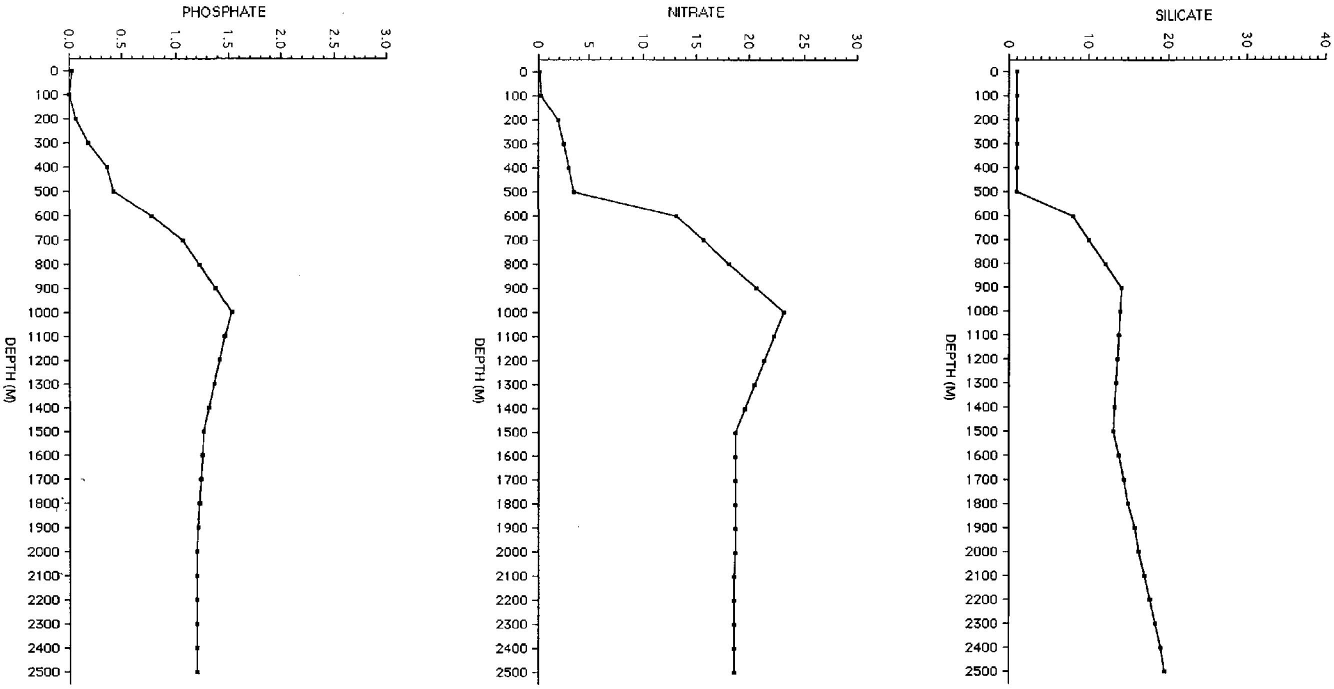


FIGURE 75 (Cont.). Typical depth profiles showing the vertical distribution of nine oceanographic parameters in the vicinity of the shipwreck. Temperature (°C), salinity (‰), density (σ_t), sound velocity (m/s), oxygen (ml/l), and pH profiles represent typical late summer conditions and phosphate (µg-atoms/l as P), nitrate (µg-atoms/l as N), and silicate (µg-atoms/l as Si) profiles show early spring conditions.

of organic detritus as well as by respiration of sinking plants and animals. Thus, an oxygen minimum layer develops where the maximum consumption of oxygen occurs.

NODC data gathered near the site universally showed a marked oxygen minimum layer at depths below 600 m and above 1,000 m. Generally the concentration of dissolved oxygen fell from between 4.4 and 6.3 ml/l at the surface to between 3.1 and 3.6 ml/l (annual mean 3.34±0.15) within the minimum layer. The level of oxygen saturation also fell from an average of 109% for surface waters to 71% in the minimum layer. The boundaries of the layer were usually sharp with typical concentration gradients of 0.5 to 1 ml/l in 100 m (Fig. 75). The thickness of the layer ranged from 76 to 205 m (mean 110 m) with the mean depth of the upper boundary at 710 m and the mean lower boundary at a depth 825 m. The shallowest depth of the upper boundary was 600 m and deepest depth of the lower boundary was 1,012 m. Below the minimum layer the oxygen concentration recovered rapidly and generally ranged from 4.0 to 6.4 ml/l down to the seabed.

Emery and Uchupi (1972) reported that the depth of the minimum content of oxygen in the western North Atlantic Ocean is least near the continental slope (220 to 300 m) but seaward from the Gulf Stream the depth increases abruptly to 800 to 900 m within the Sargasso Sea. They further reported that where the oxygen minimum was at depths of 600 to 700 m, oxygen increased only gradually below the minimum value so that the zone of low oxygen content reached to depths of several kilometers. However, NODC data from the continental slope in the vicinity of the shipwreck does not confirm this contention. As noted above, these data demonstrate that oxygen concentrations below 2,000 m approach or exceed surface values (Fig. 75).

At the shipwreck site, the rise in oxygen levels at depths below the minimum layer appeared to be related to the input of cold, dense, oxygenated water sinking in polar regions. The oxygen content near the seabed represents a steady-state balance between biological activity and physical replenishment by currents, primarily North Atlantic Deep Water from the Norwegian Sea and secondarily Antarctic Bottom Water.

Abyssal Conditions. The character of the bottom water at the shipwreck site was defined by analyzing the NODC data set for deep measurement stations in the vicinity of the shipwreck. The station data, which was collected in all four quarters of the year over a 34-year period, represents both annual and long-term variations in parameter values. The range, mean, and standard deviation for the parameters were measured at the 28 deep-profile stations (Table 10).

One of the most obvious characteristics of the seawater immediately surrounding the shipwreck was its remarkable physical and chemical stability. Temperature varied less than 1° C, salinity less than 0.2‰, density less than 0.0002 g/cm^3, dissolved oxygen less than 2 ml/l, and pH less than 0.2 units. The biological nutrients (phosphates, nitrates, and silicates) were less conservative in their variability but they too were relatively constant in comparison to upper water column fluctuations. Other noteworthy features were the high dissolved oxygen concentration, which was anticipated given the

TABLE 10

Oceanographic data for seawater at the approximate depth of the SS Central America *shipwreck.*

Parameter	Units	Range	Mean ± SD
Depth	(m)	1,905-2,500	2,192±225
Temperature	(° C)	2.81-3.77	3.38±0.25
Salinity	(‰)	34.90-35.06	34.97±0.03
Density	(σ_t)	27.79-27.90	27.85±0.03
Sound velocity	(m/s)	1,497.1-1,505.6	1,500.8±2.9
Dissolved oxygen (O_2)	(ml/l)	5.85-6.40	6.13±0.15
Oxygen saturation	(%)	79-87	83±2
Inorganic phosphate (PO_4)	(µg-atoms/l)	1.20-1.82	1.41±0.22
Nitrates (NO_3)	(µg-atoms/l)	17.0-23.9	20.1±2.6
Silicates (SiO_3)	(µg-atoms/l)	12.0-25.9	16.1±4.5
Hydrogen ions (H^+)	(pH)	7.99-8.14	8.07±0.06

high degree of iron oxidation observed on the shipwreck, and the high concentration of dissolved nutrients, which was also anticipated because of the lack of photosynthetic productivity to utilize microbial degradation products.

MARINE GEOLOGY

Bathymetry

Off Cape Hatteras, a generally north-south, discontinuous ridge lies between the deep-ocean basin (Hatteras Abyssal Plain) and the continental slope; the ridge extends to the Caribbean Sea. The largest segment of this feature is the Blake Ridge (also known as the Blake-Bahama Outer Ridge) which extends southward from the northern end of the Blake Plateau, gradually becomes lower, and finally terminates east of the Bahama Islands (Fig. 58) (Schneider and Heezen 1966). The Ridge is a sedimentary spur with gentle slopes, typically less than 3°. Seismic-reflection profiles across the Ridge show that this feature is a sedimentary deposit that accumulated on relatively flat oceanic crust. Beginning as a feature kilometers thick in the northwest, this sedimentary tongue diminishes toward the southeast where it is only a few tens of meters thick (Ewing and Ewing 1964). The sedimentary horizons within the Ridge are uncomplicated by faulting and folding and do not appear to have been deformed by plate tectonic processes. The dominant morphologic form of this Ridge was caused by hemipelagic deposition of continentally derived sediment, primarily lutite. This deposition was most likely controlled by the southerly flowing Deep Western Boundary Current. This current has been found to be strongest below depths of 3,000 m (Swallow and Worthington 1961). The area surveyed to locate the shipwreck extended from the crest to the northeast flank of the Ridge in water depths that ranged from 1,800 to 3,000 m. Interestingly, the shipwreck of the SS *Central America* rested on biogenic sediments rather than lutite. The crest of the Ridge, where the shipwreck was found, apparently is less subject to terrestrial sediment than the flanks.

Photographic investigations of the orientation of sedimentary bedforms (e.g., sediment streamers, asymmetrical ripple marks, accumulations on updrift sides of obstructions, and other current markings) on the Blake Ridge indicate that the Deep Western Boundary Current had transported and deposited sediment in a southerly direction parallel to the bathymetric contours of the Ridge (Schneider and Heezen 1966). These geotrophic contour-following currents may have played a dominant role in the shaping of the Ridge (Heezen et al. 1966). Photographs from the present study confirmed the dominant southerly movement of the sediment under the influence of the Deep Western Boundary Current. A sizable accumulation of pteropod ooze and *Sargassum* mats had taken place in a 10-month period, adjacent to wood test panels set near the shipwreck site in September 1990 (Fig. 76). By comparison, Site H (approximately 60 km to the east) appeared to be more tranquil as indicated by the biologically tracked seafloor at this location (Fig. 59). The depth at Site H was 2,400 m, about 200 m deeper than at the SS *Central America* shipwreck.

Sedimentology

The bottom at the site consisted of minute calcareous and siliceous shells of protozoans and molluscs (silt- and sand-sized particles) which lived in the euphotic waters (upper zone of the ocean in which there is sufficient light to support photosynthesis). When these organisms died, the living matter was consumed by other animals or decomposed by bacteria and only their shells settled to the deep-ocean floor. The sediments surrounding the shipwreck site almost completely lacked those terrigenous components of sediment found nearer to the coast that would be transported in from continental streams or blown in by offshore winds.

Deposition of marine sediments seaward of the Blake Escarpment in the early Cretaceous (140 million years BP) initiated the formation of the Blake Ridge (Markl and Bryan 1983). The deposit is wedge-shaped, thinning toward the southeast and approximately 8.5 km thick at its base (northwestern end) near the location of the SS *Central America* shipwreck. Built on oceanic basement rock, this major topographic feature is one of the world's largest sediment ridges (Markl and Bryan 1983).

The seafloor surrounding the shipwreck site was largely composed of *Globigerina* ooze (60 to 80%) which consisted mainly of the calcite tests of pelagic, and some benthic, foraminiferans. Lesser amounts of another type of shell, composed of aragonite, was also found in the ooze, the remains of pteropods (pelagic gastropods). Pteropods normally comprised less than 20% of the shell material in these upper Blake Ridge sediments. However, within the hull of the SS *Central America*, the proportion of

FIGURE 76. The submersible *Nemo* deploys science experiments near the shipwreck of the SS *Central America*. Two rows of wood posts (60 x 10 x 10 cm) are placed in the sediment ooze to attract the wood-boring bivalves believed to be responsible for the destruction of the ship's timber. The front row is pine and the back row oak to simulate the timbers used to construct the ship. *Nemo* is deploying canisters with various types of textiles to test the effects of submergence in the deep ocean. Mats of *Sargassum* weed have accumulated at the base of the post (in snow-fence fashion) by southwesterly bottom currents. The sediment in the right side of the photograph is pteropod ooze that merges with foraminiferal ooze along the line of posts. The posts may have been responsible for the deposition of the coarser pteropods on the up-current side.

pteropods increased to about 60% of the sediment—a pteropod ooze (Fig. 77). The ratio of foraminiferans to

FIGURE 77. Sample of pteropod ooze recovered from the shipwreck site. This material forms the bulk of the sediment within the hull area of the SS *Central America* shipwreck. The sediment is composed of the aragonite shells of pelagic snails that had settled from the ocean surface. Approximately 15 species of pteropods were found in this sample (see Appendix A and Table 9). The fine-grained particles are foraminiferan tests. The diameter of the sample container is 10 cm.

pteropods raining down on the ocean floor was most likely a relatively uniform 5:1 for this portion of the North Atlantic Ocean (Table 8). The wreck, which rose several meters above the bottom, probably modified the bottom currents and resulted in hydrodynamic acceleration which washed away the fine-grained foraminiferan tests, leaving the larger pteropods behind as a lag deposit (Fig. 76).

A number of minor sedimentary structures were observed on the ocean floor in the vicinity of the shipwreck. Ewing and Davis (1967) developed a morphologic classification system for such structures thought to be produced by living organisms. These structures, known as *Lebensspuren*, were abundant in the foraminiferal ooze, particularly at Site H. Following their classification scheme, one of the most conspicuous groups of structures was designated IVBI—depressions arranged in a circle with a single row of holes on the circumference (Fig. 78). These types of structures are commonly known as "fairy rings." The circles, which were slightly domed in the center, ranged in diameter from about 10 cm to over 30 cm, and the pits, of which some were circular and others were elliptical, numbered from about 20 to 50. In most cases the pits formed a complete ring around the periphery of the structure. The origin of these structures

FIGURE 78. Foraminiferal ooze at Site H. The sediment surrounding the shipwreck at Site H is a fine-grained ooze composed largely of foraminiferal tests and lesser quantities of pteropod shells. The circular impressions, known as "fairy rings," are probably caused by benthic animals but their exact origin is unknown.

is problematic. Gage and Tyler (1991) listed them as being of unknown origin but Morton and Miller (1973) noted similar structures in shallow sediments and attributed them to brittle stars permanently buried in tidal flats. Neil (1991) photographed deep-sea depressions of a similar design in the Bounty Trough, southwest Pacific Ocean, and also concluded they represented feeding patterns made by ophiuroids after burrowing into the sediment.

Much larger scale elliptical patterns in the seafloor were noted on side-scan sonograms of the search area. The major axes of the ellipses were in the range of 50 m and ten or more often occurred in a field. The patterns appeared to be either structural depressions or textural variations. Dr. Paul R. Dando, Marine Biological Association, Plymouth, England, suggested that these patterns may have been associated with methane seeps. He and his colleagues observed a "pockmark" 200 m across and 10 m deep in North Sea sediment that was an active methane seep (Dando et al. 1991). Ice-like substances called gas hydrate form at temperatures well above freezing when certain gases, such as methane, are combined with seawater at elevated pressures. The presence of gas hydrate has been shown to markedly change the acoustic wave velocity and other physical properties of the sediment (Stoll 1974). Unusually high seismic velocities in gas-rich sediments of the Blake Ridge (Bryan 1974) suggest the possibility of gas hydrate deposits in the upper few hundred meters. The occurrence of such deposits in the search area may explain the peculiar elliptical images.

Several major rivers enter the ocean along the Carolina-Georgia coast. These streams are the most likely ones to have contributed sediment to the continental shelf that eventually found its way to the continental slope in the vicinity of the SS *Central America* shipwreck. The mean monthly combined discharge of these streams ranges from 1,000 to 4,000 m^3/s (annual average 2,200 m^3/s) for an annual total of nearly 7.0 x $10^{10} m^3$ (Blanton and Atkinson 1983). Typically, these streams carry 1,000 mg/l of suspended sediment (Gehm and Bregman 1976) for a combined estimate of 3.5 x 10^7 m^3 of sediment per year. If this material was deposited uniformly over the shelf and slope offshore of these streams out to the position of the shipwreck, the average annual sedimentation rate would be about 0.3 mm/yr or about 40 mm since the time of the sinking. However, most of the deposition from these streams takes place in the estuaries or on the shelf and relatively little finds its way 270 km offshore. Particle counts showed that less than a quarter of the sediment at the shipwreck site was composed of non-shell material that might have originated in terrestrial streams. Based on sedimentation rates for the site (17 mm/1,000 yr, obtained from radiocarbon dating of a sediment core), the stream-derived material probably amounted to only 0.6 mm since the sinking (<0.005 mm/yr). Thus, at 270 km offshore, the deposition of stream-derived sediment is only a minor factor in the potential burial of cultural artifacts.

In September 1989, a 50-cm sediment core was obtained in the mixed foraminiferal/pteropod ooze adjacent to the shipwreck. The material consisted of a surface layer (5 cm thick) that contained considerable rust fragments indicating the limit of penetration and mixing by benthic invertebrates (bioturbation). This layer also had the highest concentration of pteropod shells. The remainder of the core was a relatively uniform and fine-grained foraminiferal ooze, accented by occasional layers of coarser material which contained more pteropod shells. The core was segmented into five units below the surface layer, generally at the thin coarse horizons. Sub-samples from these units were submitted to Geochron Laboratories of Cambridge, MA, for radiocarbon (C^{14}) dating (Table 11). The bottom of the core yielded a date of 26,400 years BP (before present), indicating a mean sedimentation rate of 1.0 cm in 587 years or 1.7 cm per millenium. The rate was relatively consistant for higher portions of the core, with the lowest rates being found for the period of maximum continental glaciation (9,700 to 22,330 years BP). Much of the shipwreck was not covered with sediment and was clearly exposed to view. The very slow sedimentation rate determined for the site and the occasional benthic storm, may explain why the wreck was not covered by ooze.

MARINE BIOLOGY

The *Central America* shipwreck was discovered in a barren and changeless environment—one of near silence, utter darkness, enormous pressure, and temperatures only a few degrees above freezing. The silt/sand seabed of the Blake Ridge supported little in the way of visible marine life and could aptly be described as a deep-ocean desert. Yet, in the years since the *Central America* tragedy, the wreckage was transformed from a lifeless hulk into an oasis which teemed with marine life. This has posed many questions for biologists working on the site, among them:

1. What types of ecological disturbances resulted from the shipwreck?
2. How did a biological oasis form in the midst of a deep-sea desert?
3. Why were the animals more diverse and in greater abundance on the shipwreck than on the surrounding seafloor?

TABLE 11

Radiocarbon (C^{14}) age determinations for a sediment core taken at shipwreck of SS Central America.

Depth Interval (cm)		Radiocarbon Age (yrs BP)	Years Diff.	Depth Diff. (cm)	Sedimentation Rate (yrs per cm)		Sedimentation Rate (cm per 1,000 yrs)	
A	5-11	4,335±145			542		1.8[1]	
			1,035	6		173		5.8[2]
B	11-17	5,370±165			386		2.6	
			4,335	6		723		1.4
C	17-23	9,705±250			485		2.1	
			12,625	11		1,148		0.9
D	25-37	22,330±420			720		1.4	
			4,070	14		291		3.4
E	40-50	26,400±2,050			587		1.7	

[1]Cumulative rate from surface.
[2]Interval rate.

Location: North Atlantic Ocean (32° N, 77° W)

Depth: 2,200 m

Geochron Laboratories Sample Nos.
A. GX - 15524
B. GX - 15525
C. GX - 15526
D. GX - 15527
E. GX - 15528

4. Are the animals on the shipwreck indigenous or did they migrate from multiple regions of the ocean?
5. Originally, how and from where did these animals obtain enough nutrition to survive?
6. What types of food chains and food webs and other animal interactions occur on the shipwreck?
7. What special adaptation do the animals on the shipwreck have for survival?
8. What is the stage of ecological succession on the shipwreck and how long will the shipwreck ecosystem survive?
9. What future transformations will take place in the shipwreck ecosystem?
10. Will pre-disturbance conditions be restored?

To answer these questions, the composition of the biological community on the shipwreck and the population densities of dominant species first had to determined. Next, the association of deep-sea animals to the shipwreck had to be ascertained. To do this, experiments were initiated to study interrelationships between the shipwreck and the animals living on it, and to determine the interactions among the animals. Building on these observations, other experiments were undertaken and others are yet to be designed, to answer some of the more difficult questions. The documentation of the types of animals utilizing the shipwreck as a habitat is well under way and several experiments have been initiated to understand how this isolated, deep-ocean ecosystem functions. This section of the paper documents the marine life found at the shipwreck site and discusses experiments which probed the ecosystem.

The biological richness and diversity observed on the shipwreck of the SS *Central America* was remarkable. Every major class of deep-sea benthic life was represented. Approximately 175 taxa of macroscopic animals (Appendix A), as well as numerous microscopic forms, were documented. This section of the paper examines the benthic and benthopelagic communities which have colonized the shipwreck, emphasizing the macroscopic members that could best be documented by the cameras and sampling techniques of the submersible *Nemo*. For each major taxonomic subdivision, there is presented a general description of the group's morphology and structure, modes of locomotion and food gathering, and reproductive strategies, particularly as these features relate to a deep-ocean existence. Specific observational information on the individual species and their behavior is presented by taxonomic groupings. The inclusion of background information is intended to provide a context for animals living on the shipwreck and to show how they coped with constraints of the deep-ocean environment. The classification of invertebrate animals used in this paper follows the taxonomic system published in Parker (1982), while the classification used for fishes follows that of Eschmeyer (1990).

DEEP-OCEAN ENVIRONMENT

The shipwreck of the SS *Central America* fostered a deep-sea ecosystem quite different from the monotonous foraminiferal ooze which surrounded the wreck for many kilometers. The wooden hull and decks, the massive ironworks, the abundant piles of boiler coal, and even the gold provided diverse habitats for an intricate food web ranging from bacterial decomposers to large piscivorous fishes. In the dark, silent and cold world, at a depth of 2,200 m, deep-sea creatures lived in an almost unchanging but harsh environment—a world where it was perpetual night and there were no seasons.

Animals living here had to endure intense cold and immense pressure. Southerly flowing water masses, which originated in the sub-Arctic North Atlantic Ocean, continually flushed the site with gentle oxygen-rich currents. Occasional benthic storms resulted in current reversals with velocities that approached 1.0 m/s. The shipwreck, which at places rose 5 to 7 m above the bottom, appeared to accelerate currents within the site which had effected sediment erosion and deposition patterns. The normal deposition rate surrounding the site was very slow, only a few centimeters in the past millennium. Some areas of the shipwreck were scoured clean, while others had over a meter of post-sinking sediment deposits.

MICROORGANISMS

Microbes (bacteria and fungi) living in the deep sea are characterized by being tolerant of (and probably requiring) an environment with low temperatures (psychrophilic), high pressure (barophilic), and limited food resources (Kushner 1978). These factors account for the low level of deep-sea bacterial activity demonstrated by Zobell and Morita (1957). Excluding some nutrition which may be derived from decaying parts of the shipwreck, populations of animals and microorganisms on the ocean floor and the study site depend upon organic food materials sinking down from photosynthetically productive surface layers. At nearly 300 km off-shore, very little nutrition is introduced by runoff from the continent. Jannasch et al. (1976) speculated that the principal site of microbial activity in the deep sea was the intestinal tract of benthic animals but they also pointed out that *in-situ* microbial activity is still substantial in proportion to the amount of organic matter reaching the deep seafloor by sedimentation. As evidence, they did not observe abnormal accumulations of organic materials on the deep seafloor. However, they did observe that artificially added organic waste materials, not readily available as food for the microfauna, may decompose at a considerably slower rate in the deep sea than in shallow water (Jannasch and Wirsen 1973).

These conclusions appear to be borne out by observations at the shipwreck site. Plate counts of bacteria cultured on sediment from the site yielded numbers ranging from 1.4 x 10^6 to 2.4 x 10^6 per ml (see Abbott Laboratories analysis below), indicating a rich microbial population. However, decomposition of organic matter appeared to be slow. The elevated features of the shipwreck and even wood panels deployed as part of a wood-borer experiment (Fig. 76) functioned much the way that a snow fence does, in that sizable accumulations of *Sargassum* weed built up on their up-current sides. These accumulations persisted for several months or longer without noticeable microbial decay.

Culture Experiments

In September 1990, three samples were collected from the shipwreck site for microbiological analysis, including: 1) sediment ooze from the ocean floor adjacent to the wreck, 2) a fragment of wood from the ship, and 3) a piece of modern polypropylene rope that was discovered on the site. The samples were sealed in ambient water from the submersible's storage compartment and shipped to Abbott Laboratories in Abbott Park, IL, for analysis of fungi, actinomycetes (branched, filamentous bacteria), and non-filamentous bacteria. The analyses were conducted under the direction of senior microbiologist Dr. James P. Karwowski with the assistance of Pat Humphrey, Paul Sheldon, and Gabriela Sunga.

A 5.0 ml slurry of sediment was centrifuged at low speed to remove large pteropod shells. The supernate was used in three plating experiments. Small portions (0.2 g) of the wood and rope samples were individually placed in 1.8 ml sterile Instant Ocean® (38 g/l) salt solution and these were sonicated for one minute at output setting four using the cup horn on a Heat Systems/ Ultrasonics model W-375 Sonicator. The sonicated (mixed) samples were then plated at 10^{-2}, 10^{-3}, and 10^{-4} dilutions.

Plating for Fungi. Each sample was plated on the following four media: 1) cornmeal agar (CMA), Difco no. 0386-01-3, 2) Emerson YpSs agar (YpSs) Difco no. 0739-01, 3) 5% malt extract agar (MEA), Difco malt extract no. 0186-01 and 16 g/l agar, and 4) marine agar (MA), Difco marine broth 2216 no. 0791-01 and 16 g/l agar. All these media were prepared with Instant Ocean salts solution and all contained 60 μg/ml streptomycin sulfate (Sigma). The sediment was plated on media adjusted to the pH of the sediment sample (pH 6.9). The wood and rope samples were plated on unadjusted media.

Plating for Actinomycetes. Each of the three samples was also plated on the starch casein (SC) and glycerol glycine (GG) media described by Okami and Okazaki (1978). The GG medium was prepared with distilled water and with Instant Ocean salts, while the SC medium was prepared only as described by Okami and Okazaki. The samples were also plated using the procedure described by Pisano et al. (1989). The medium in this case was prepared with and without Instant Ocean salts. The samples were also plated by five proprietary techniques designed to isolate a variety of actinomycetes.

Plating for Bacteria. All three samples were plated on yeast extract agar (YEA) as described by Baumann and Baumann (1981) and on the marine agar described earlier. The samples were plated for *Bacillus* species by the method of Wakisaka and Koizumi (1982) with media prepared with distilled water and with Instant Ocean salts and for arthrobacteria using the procedure of Hagedorn and Holt (1975).

All plates were incubated at 15° C until colonies were observed. Typically, bacterial plates were incubated for three days, fungus plates for five days, and actinomycetes for three weeks.

Fungi Results. Although the fungus isolation media contained streptomycin to inhibit the growth of bacteria, large numbers of non-filamentous bacteria were observed on all plates. Streptomycin was included in the media because it is quite effective in controlling terrestrial bacteria. It will be necessary to test other antibiotics to find ones that would inhibit marine bacteria. A number of colonies were selected from the plates; all were

Gram-negative rods. Plate counts are shown below:

Plate counts of bacteria from three marine samples grown on four media:

Source	MA	MEA	CMA	YpSs
Sediment	2.4 x 10^6	1.7 x 10^3	1.4 x 10^6	1.4 x 10^6
Wood	1.5 x 10^5	6 x 10^2	3.8 x 10^4	3.9 x 10^4
Rope	3.9 x 10^6	8.8 x 10^3	1.8 x 10^5	5.2 x 10^5

Note: figures indicate the number in 1 ml of prepared sample.

The only fungi observed were seven yeast colonies which were obtained from the sediment sample plated on marine agar. These isolates appeared to be two different types of ascomycete fungi (yeasts).

Actinomycetes Results. No actinomycetes were observed on any of the actinomycete isolation plates. No non-filamentous bacteria were observed in any of the proprietary experiments. All these media contained 25 µg/ml of the antibacterial agent novobiocin. Non-filamentous bacteria grew on all media plated by the Okami and Okazaki and the Pisano techniques. In all cases plate counts exceeded 10^6 bacteria per ml plated.

Bacteria Results. The technique for isolation of *Bacillus* species yielded 10^3 to 10^4 non-filamentous bacteria per ml only on media prepared with distilled water. The same medium prepared with Instant Ocean salts showed no growth indicating that the isolates were not true marine forms. All the samples plated on YEA and MA gave greater than 10^6 bacteria per ml. Most of the cultures appeared to be similar yellow-pigmented organisms although there were some white colonies. No colonies were observed on the media plated to find arthrobacteria. The Gram reaction and morphology of these bacteria were tested. Thirty six cultures isolated on YEA and another 29 obtained by the Okami and Okazaki and the Pisano techniques were transferred to MA and grown for 18 hours at 15° C. After staining, microscopic observation revealed that 60 isolates were Gram-negative rods. Five cultures were Gram-positive; three of these were rods and two were cocci.

In summary, three samples obtained from the SS *Central America* were plated on a variety of media designed to isolate fungi, actinomycetes, and non-filamentous bacteria. No actinomycetes were found by procedure. Two different types of yeast were the only fungi observed. These were found in the sediment sample. Large numbers of non-filamentous bacteria were seen on all isolation plates except when novobiocin was present in the plating medium. The majority of the bacteria found in this study were typical marine forms, being Gram-negative, yellow-pigmented rods.

Bacteria and Fungi

The laboratory results indicating the presence of non-filamentous bacteria on the seafloor have received confirmation from related studies of shipwreck artifacts. Dr. Kathryn A. Jakes, Department of Textiles and Clothing, The Ohio State University, observed both rods and cocci bacteria on the textile linings of leather passenger luggage recovered from the shipwreck site in 1990 and 1991. SEM photomicrographs were made of bacteria found in linen linings in the Easton trunk (Figs. 79, 80).

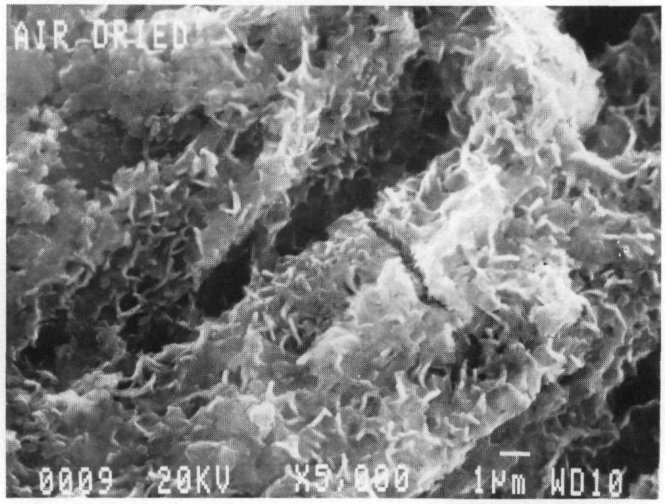


FIGURE 79. Scanning electron microscope photomicrograph of bacteria found in the linen lining of the Easton trunk. Magnification: 5,000X. Photomicrograph courtesy of Dr. Kathryn A. Jakes.

Other contents of the trunks are discussed in the Underwater Archaeology section later in this paper.

Research conducted by the authors in conjunction with Dr. Eleanora I. Robbins, geologist, U.S. Geological Survey, has shown that the filamentous bacteria *Leptothrix* was an important facilitator in the formation of iron scale and the flow features known as "rusticles" that were so prevalent on the shipwreck. This topic is discussed in detail in the Materials Science section later in this paper.

Kohlmeyer (1969) found that wood panels exposed for one to three years in the North Atlantic Ocean at depths between 1,600 and 2,100 m were attacked by cellulose digesting fungi. He was also able to isolate ascomycete fungi in samples taken at a depth of nearly 4,000 m. Similarly, Thiel (1975) reported the presence of fungal infections in sediment samples from a depth of 2,500 m in the North Atlantic Ocean (0.1 infections units/ cm^2). Accordingly, fungi were suspected as one of the

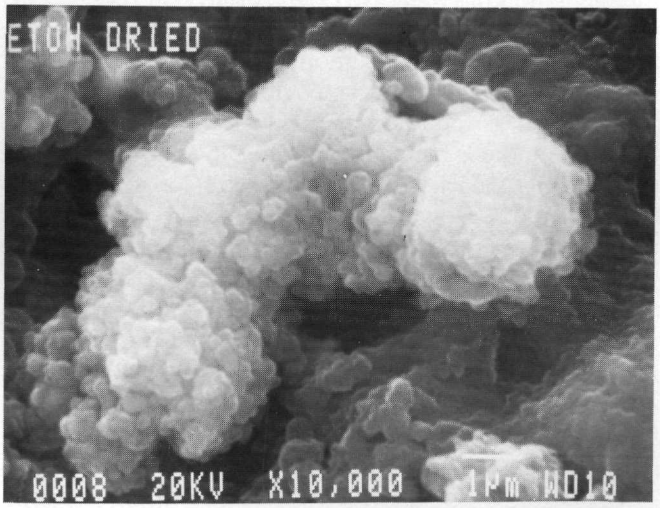


FIGURE 80. Scanning electron microscope photomicrograph of bacteria found in the linen lining of the Easton trunk. Magnification: 10,000X. Photomicrograph courtesy of Dr. Kathryn A. Jakes.

agents responsible for the degradation of the wood hull and decks of the SS *Central America*. In August 1990, a freshly recovered timber from the shipwreck was sent to Dr. Jan J. Kohlmeyer, marine mycologist, University of North Carolina, for examination. The sample failed to yield any evidence of fungal growth. Dr. Kohlmeyer concluded that at some period in the past, the wreck (or at least the portion of the wreck from which the timber was recovered) had experienced anoxia, eliminating any fungi and wood-boring bivalves from the timber. However, video images of a bottom-browsing ophidiid fish (*Barathrodemus manatinus*) at the shipwreck site in September 1989 did reveal what appeared to be an infection of a parasitic fungus. The bluish-gray fish had a distinctive white, cotton-like patch near its opercular flap that was about 1 cm in diameter.

PLANT DIVISIONS

DIVISION PHAEOPHYTA: Family Sargassaceae

Sargassum weed or gulfweed is a brown alga (Phaeophyta)—a group of marine plants which includes the largest seaweeds in the oceans. Mature forms consist of a blade (leafy structure), stipe (stem-like organ), and in many, a holdfast for anchoring the plant to a substratum. Most also have pneumatocysts which are gas-filled floats located on the stipe. The floats keep the blades from sinking out of the sunlit region of the sea. *Sargassum* grows in the Caribbean Sea and the Gulf of Mexico but during storms it breaks free and is swept into the center of the North Atlantic current gyre, giving the Sargasso Sea its name. The floats in turn give the weed its name, from the Portuguese word for grape, *sargaço*. A few species (e.g., *Sargassum fluitans* and *S. natans*) lead a pelagic life. These form loose masses and tangles of seaweed which grow up to several meters in diameter but the individual segments are often relatively short. Floating *Sargassum* spp. was the most characteristic plant life observed over the shipwreck site at the boundary between the Gulf Stream and the Sargasso Sea.

The open water species have lost their capacity for sexual reproduction and rely entirely upon vegetative fragmentation. Dawes (1981) suggested that these forms are derived from detached littoral species that, through the slow process of evolutionary adaptation, have become truly pelagic. The biological productivity of the Sargasso Sea is regarded as relatively low, in large part because of the permanent thermocline (400 to 500 m deep) which blocks the upward diffusion of nutrients (Gordon 1966). However, Parr (1939) estimated a significant standing crop of 4 to 11 million tons of *Sargassum* weed in the Sargasso Sea, far too much to be maintained by castaways from coastal beds.

Collections of pelagic *Sargassum* with an oceanographic plankton net from on board the R/V *Arctic Discoverer* showed the seaweed to harbor a community of camouflaged shrimp, crabs, pipefish, small pteropods, coelenterates, bryozoans, ctenophores, polychaetes and numerous other forms. Loose masses and tangles of *Sargassum* weed were continually noted on the ocean surface above the wreck site but generally the segments were relatively short (20 cm) and the mats were widely scattered and rarely over a meter in diameter.

Two species of *Sargassum* are free-floating in the Sargasso Sea: 1) *S. natans*, often called sargasso weed and 2) *S. fluitans*, sometimes called gulfweed. The former species forms floating clumps with pale brown to yellow-green, elongated, narrow blades and spiny margins on thin, wiry branches (center and lower left of Fig. 81). Numerous spherical bladders (pneumatophores or floats) are connected to the main stipe by an elongated stalk. A distinguishing character is a small spine, hooked spur, or leaflike projection that appears at the tip of each bladder. The blades lack the small, dark dots (cryptostomata) observed on most attached species of *Sargassum* when the blade is held up to a bright light (Littler et al. 1989). Growths of *S. natans* generally have no single, distinct, main axis or branch but are composed of clusters of branches. Individuals may reach a length of 50 cm and are often found floating alone or in large clumps or rafts.

The other species, *Sargassum fluitans* looks more robust than *S. natans* (see upper right of Fig. 81). Round, spineless, bladders are set along a smooth stipe. The thin, flat blades are golden brown to yellow-green with a prominent midrib and pointed teeth on the margins. They are short-stalked and numerous but not dense, on widely spreading cylindrical branches. Like *S. natans*, the blades lack cryptostomata. Individual plants may reach lengths up to 1 m. This species is strictly free-floating (no holdfast at base of stipe) in open ocean waters and is often found in large clumps or rafts.

Noted from the *Arctic Discoverer*, *Sargassum* weed was normally aligned in long rows oriented in the direction of the wind. The rows changed their direction following a change in the wind. Langmuir (1938) concluded that such windrows are regions of convergence caused by water circulation with alternate right-and left-helical vortices which have their axes in the direction of the wind. Such water motion is often called Langmuir circulation. *Sargassum* weed collects on the convergence line of the surface current where two water masses meet and sink. The spacing of weed rows in the North Atlantic is proportional to the velocity of the wind: 4 m/s (15 km/hr) winds produce a spacing of about 20 m whereas 12 m/s (60 km/hr) winds yield a spacing of about 50 m (Faller 1964). During calm weather, *Sargassum* weed floats close to the surface supported by numerous gas-filled bladders. When strong winds blow, localized descending currents are set up which drag the plants below the surface. As *Sargassum* descends, the increasing hydrostatic pressure compresses the gas bladders and reduces buoyancy. Experiments with *Sargassum natans* suggest that the plant could sink as low as 100 m and still be lighter than the surrounding sea (Woodcock 1950). However, if the plant was driven below the 100-m level by strong currents, it would continue to sink to the ocean floor. Johnson and Richardson (1977) proposed that healthy *Sargassum* is transported vertically into the deep ocean by wind-induced Langmuir circulation. The occurrence of abundant accumulations of *Sargassum* on the shipwreck site supported this contention.

Noteworthy observations of *Sargassum* on the ocean floor were made shortly after the passage of Hurricane

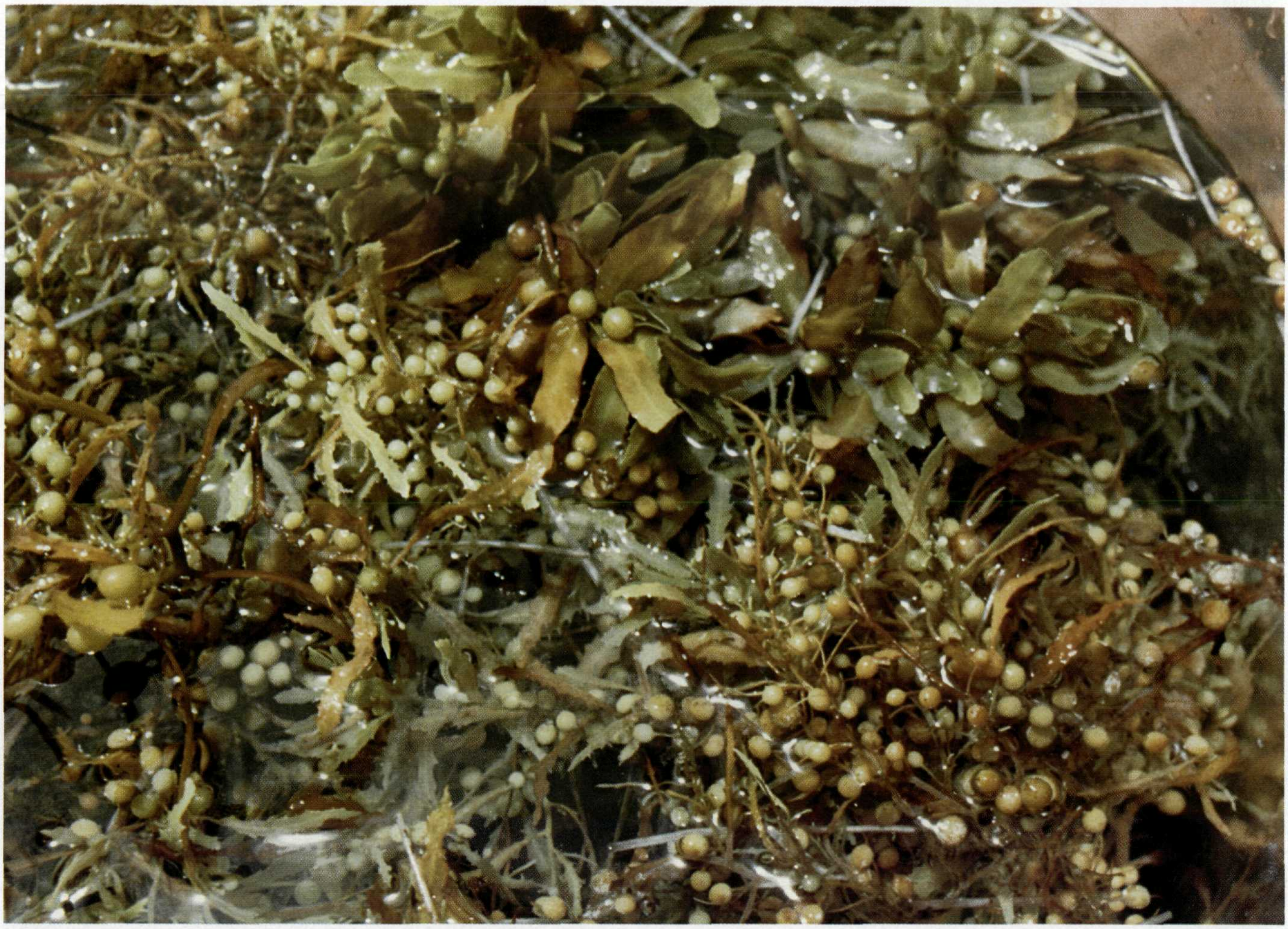


FIGURE 81. Mat of floating *Sargassum* weed sampled from the deck of the R/V *Arctic Discoverer*. Two species are prevalent in this mat, *Sargassum fluitans* (upper right) and *Sargassum natans* (lower left). Fresh accumulations of these algal masses were also recovered from the shipwreck site.

Hugo on 19 September 1989. Submersible dives were suspended for ten days because of the storm. Video transmissions from the first dive following the hurricane showed a high density of *Sargassum* around the shipwreck. As *Nemo* prepared for a landing, mats or "balls" of *Sargassum* moved across the bottom and resembled rolling tumbleweed. Retrieved specimens of *Sargassum* from the ocean floor appeared to be in a relatively "fresh" condition. Such densities were not observed prior to the hurricane.

Images obtained in August 1991 of wood test panels (set in the shipwreck debris field in September 1990) showed windrows of *Sargassum natans* that had accumulated at the base of the panels. The material was still green and relatively fresh in appearance. Black long-spined sea urchins (similar in appearance to *Phormosoma* sp. or *Echinus* sp.) were commonly observed in association with the accumulations, presumably finding food items in the mats of weed.

DIVISION CHRYSOPHYTA: Order Coccosphaerales

This order, in the class Chrysophyceae, contains the coccolithophores, examples of which were found in the sediment and on artifacts recovered from the shipwreck of the SS *Central America*. Coccolithophores are single-celled members of the nannophytoplankton that have numerous calcareous plates (coccoliths) embedded in the cell wall. In the Sargasso Sea a single species of coccolithophore, *Emiliania huxleyi*, is responsible for most of the photosynthetic production (Sumich 1992). While conducting a scanning electron microscope examination of the surface metallurgy of a gold coin recovered from the shipwreck site, Dr. Gary Cygan, geochemist, and James Palmer, microscopist, U.S. Geological Survey, observed what appeared to be the plates of this species.

DIVISION CHRYSOPHYTA: Order Pennales

This order, in the class Bacillariophyceae, contains the pennate diatoms, examples of which were found on artifacts recovered from the shipwreck. Diatoms are large unicellular members of the phytoplankton that have cell walls (frustules) composed of pectin and silica. While examining the same $3 gold coin that yielded the coccoliths, Dr. Gary Cygan and James Palmer, U.S. Geological Survey, using an SEM-EDXA system (Moniz 1992), obtained a high silicon peak for a surface encrustation of diatom frustules. Similarly, Dr. Kathryn A. Jakes, Department of Textiles and Clothing, The Ohio State University, observed diatoms on textiles found in a leather trunk recovered from the shipwreck site in October 1991. She was able to obtain a SEM photomicrograph of a pennate diatom found on flax fibers of the linen lining in the John Dement trunk (Fig. 82; see Underwater Archaeology section later in this paper). Dr. John McNeill Sieburth, Departments of Oceanography and Microbiology, University of Rhode Island and Dr. Gary L. Floyd, Department of Plant Biology, The Ohio State University, confirmed the identification of this specimen.

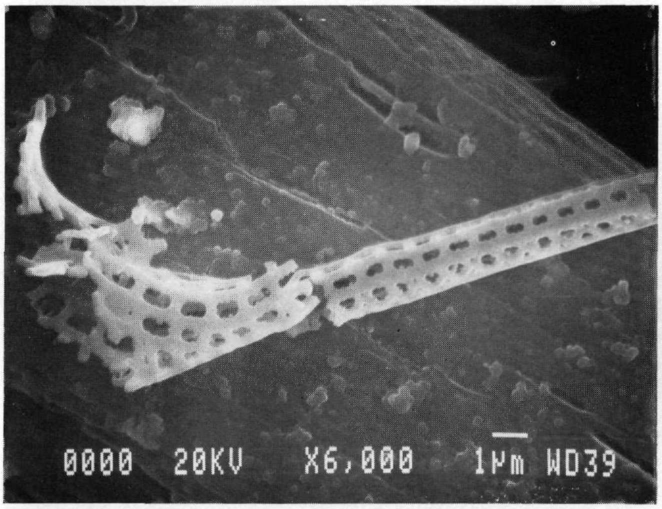


FIGURE 82. Scanning electron microscope photomicrograph of a spine from a pennate diatom frustule found on a textile from the Dement trunk. Magnification: 6,000X. Photomicrograph courtesy of Dr. Kathryn A. Jakes.

DIVISION SPERMATOPHYTA: Family Pinaceae

Wood recovered from the shipwreck of the SS *Central America* has been identified by Dr. Lee Ann Newsom, paleoethnobotanist, Florida Museum of Natural History, as one of a group of species known as the pitch or southern hard pines, most likely longleaf pine (*Pinus palustris*). These pines cannot be separated on the basis of wood structure alone, density is also important (Panshin and de Zeeuw 1980). They are characterized by being coarse-grained and generally dark colored. Longleaf pine frequently grows to heights of 30 to 37 m, with a tall slightly tapering trunk from 60 to 100 cm in diameter. The light red to orange-yellow heartwood is hard, strong, durable, and resinous. Longleaf pine heartwood averages 7 to 10% resin, while the stump is about 25%. The wood, when air dried, has a specific gravity ranging from 0.62 to 0.66, as compared to 0.54 for green wood (Collingwood and Brush 1964, Panshin and de Zeeuw 1980). Longleaf pine is generally confined to a 200-km wide belt of late Tertiary sands and gravels stretching along the coast of the Atlantic and Gulf states, from southeastern Virginia to the Florida Everglades, then westward to eastern Texas (Sargent 1965). Only 1% of the original pre-settlement 33 million ha remained by 1980, being heavily impacted by logging and naval stores industries (chiefly the production of turpentines) (Harlow et al. 1991).

Because longleaf pine is heavy, exceedingly hard, durable, has great strength, and is available in large sizes, in the nineteenth century it was favored above most other woods for construction. It was largely used for masts and spars, general shipbuilding, and interior finish for cabins. This type of wood is thought to be the primary material used to construct the ship's decks and cabins. When the SS *Central America* sank in 1857, she carried some 1,000 m^2 of wood (600 tons) to the ocean floor. This material was eventually colonized by wood-boring molluscs and other invertebrates and may have formed the initial food base for the unusual deep-ocean community which has developed on the shipwreck.

ANIMAL PHYLA

PHYLUM PROTOZOA: Order Foraminifera

Protozoans are single-celled organisms that are animal-like in that they are motile, eukaryotic, and heterotrophic. In other respects, they are a very diverse assemblage which are commonly treated as four separate phyla or subphyla: 1) Mastigophora (flagellated protozoans), 2) Sarcodina (ameboid protozoans), 3) Sporozoa (parasitic protozoans), and 4) Ciliophora (ciliated protozoans). Members of Sarcodina are significant sediment-forming organisms on the continental slope and the only conspicuous group of protozoans observed at the shipwreck site. One sarcodinian group—class Granuloreticulosa, order Foraminifera—accounted for most of the sediment ooze surrounding the wreckage. Another group—class Phaeodaria, order Phaeocalpida—comprised of radiolarians formed a minor component of the sediment ooze at the shipwreck site.

Foraminifera secrete multi-chambered shells or tests. Most of the tests found at the site were composed of calcium carbonate (calcite) extracted from the seawater. A few had thin, flexible tests composed of a proteinaceous substance and others had agglutinated tests which consisted of foreign particles, often sand grains, bound together with a cementing substance such as exhibited by *Rhabdammina abyssorum*. As a foram grows, protoplasm flows out an opening, spreads over the surface, and another test is secreted creating a second chamber. This process can continue until numerous interconnected chambers are formed, such as in *Bulimina aculeata*, *Hoeglundina elegans*, and *Globorotalia menardii* which were common in the sediment at the site. In some species, the chambers are added in a spiral pattern, as in *Ammodiscus incertus* and *Peneroplis* sp., and in others the form is more spherical resulting in a globular appearance, such as the very abundant *Orbulina universa* and *Globigerina bulloides*. Forams send out long, slender filaments through pores in the walls of the test. These exhibit a streaming movement, uniting to form a network for food capture and digestion. These pseudopodia (or reticulopodia) are also important for locomotion of the benthic forams living within the sediment ooze.

The sediment at the shipwreck site was composed largely of the tiny shells from marine animals which once lived in the sunlit waters near the ocean surface. The most common were the foraminifera. Several species of the planktonic superfamily Globigerinoidea predominated. Hence, such fine-grained sediment is commonly termed *Globigerina* ooze. Microscopic examination showed these tests to be ovoid or globular in shape, often grouped as several interconnected, flattened spheres. Planktonic forams feed on phytoplankton and zooplankton and are in turn preyed upon by higher invertebrates, such as micocrustaceans and tunicates, and their calcareous shells are excreted in fecal pellets that slowly descend to the ocean floor (Hemleben et al. 1989). During this descent the pellets may be recycled several times.

Foraminifera are dominantly marine protozoans and most genera are benthic, occurring on or in sediments at all ocean depths. Most are motile, moving slowly over the bottom by means of their reticulopods (branching and anastomosing pseudopods), while others are sedentary, using their pseudopodia as a binding agent to the substratum. Still others attach themselves permanently or temporarily to algae, corals, or molluscs, including shell fragments (Loeblich and Tappen 1964). Although the majority of the Foraminifera live on the floor of the sea, a few genera are planktonic, inhabiting the surface waters in enormous numbers. As mentioned above, globigerinoids, play an important role in the formation of sediment on the seabed. *Globigerina* ooze covers more than 100 million km^2, over one third of the ocean's floor, and includes the region of the *Central America* shipwreck. At the site, approximately 80% of the sediment was composed of the tests of planktonic forams which once lived 2,200 m above. Studies by Bé et al. (1971) indicated that 23 species were likely to live in the surface waters above the site (Appendix B) and eventually their tests would become incorporated in the sediment. However, at the site and at similar depths throughout the world ocean, relatively few planktonic genera make up the bulk of modern ocean floor foraminiferal ooze.

Calcium carbonate is one of the main components of North Atlantic deep-sea sediments at depths shallower than 3,800 m, and planktonic Foraminifera are one of the principal sources of this material. Hemleben et al. (1989) showed that calcitic shells of dead planktonic Foraminifera eventually sink in the water column as individual shells, bound within fecal pellets, or attached to amorphous/gelatinous aggregates (marine snow). A sinking speed of about 300 m/day for *Orbulina universa* and *Globigerina bulloides* has been reported by Takahashi and Bé (1984). Thus, the majority of planktonic Foraminifera in the sediment ooze at the shipwreck site may have reached the ocean floor in about a week. Considerable numbers of juvenile, planktonic Foraminifera are removed from surface populations through predation by copepods, salps, and other pelagic animals which produce fecal pellets that sink to the ocean floor. Many shells of planktonic Foraminifera were found in fecal pellets collected in sediment traps placed at a depth of 2,200 m by Wiebe et al. (1976) in the Tongue of the Ocean, off the Bahamas.

At the depth of the shipwreck, 2,200 m, very little dissolution of foraminiferal tests takes place during settlement through the water column. Emery and Uchupi (1972) showed that waters of the North Atlantic Ocean are undersaturated for calcite only below 4,000 to 5,000 m. At depths greater than 3,800 m, dissolution becomes important and globigerinoids are largely destroyed by carbonic acid (Berger 1971, Rietschel and Rohde 1984).

Some 40 to 50 species of benthic Foraminifera are likely to be found in the soft sediment surrounding the shipwreck of the *Central America*. Culver and Buzas (1980) compiled a listing of the 1,303 taxa of forams that have been reported off the North American Atlantic coast in 188 research papers published during the period 1851 to 1978. Distribution maps prepared from the results of these studies show that stations in the vicinity of the shipwreck (31° to 33° N and 76° to 78° W, at depths of approximately 2,000 m) yielded 45 common benthic species. Based on their depth classification scheme, 18 species are deep water forms (>200 m), 9 are typical of intermediate water (<200 m), and 18 are ubiquitous in their distribution. The taxonomic relationships of these species as well as the 23 common planktonic Foraminifera which contributed heavily to the composition of the deep-sea sediment at the wreck site were determined (Appendix B).

PHYLUM PROTOZOA: Order Phaeocalpida

This order contains the radiolarians, class Phaeodaria, which formed a minor component of the foraminiferal ooze at the shipwreck site. Radiolarians are also planktonic and of approximately the same size as globigerinoid Foraminifera. They posses an internal skeleton and spines composed of silica. Microscopic examination of sediment ooze samples collected from the shipwreck site in September 1991 yielded several specimens of a circoporid radiolarian, *Circostephanus coronarius*. The paneled tests were composed of numerous polygonal plates with radial, branched spines that numbered approximately 30. The specimens compared favorably with illustrations of this species in Campbell and Moore (1954).

PHYLUM PORIFERA

Sponges are the most primitive multicellular animals, possessing neither true tissues nor organs and their cells exhibit a considerable degree of independence. All sponges are sessile creatures and display little movement. They live in a great range of ocean depths and exhibit a wide variety of form, size, and color. Most sponges live in shallow marine environments but some groups, particularly the glass sponges (class Hexactinellida), live in the deep ocean. At the shipwreck site, sponges varied in height from less than a centimeter to over 15 cm. Some were radially symmetrical (especially the glass sponges) but many others were irregular and exhibited branching, massive, or encrusting growth patterns. Most sponges are white or have a drab, pale coloration, including the ones at the site, but bright colors are found in some species. Their bodies are permeated with small pores and canals through which water is constantly passed, giving the phylum its name. In most species the body is supported by a network of calcareous or siliceous skeletal elements, called spicules, or by organic fibers, called spongin. Spicules take on a variety of forms that are useful in the identification and classification of species.

In sponges, the loosely organized aggregate of cells is arranged in three basic body designs, asconoid, syconoid, and leuconoid structure, progressing from simple to complex. These are structural rather than taxonomic terms. Asconoid sponges are simple tubes with straight walls; they are always small and usually occur in clusters of fused tubes. The incurrent pores open into a large central cavity (atrium) which in turn opens to the outside through a large opening at the top of the tube (osculum). A size limitation for asconoid sponges is imposed by the fact that as the atrium increases in volume there is not a sufficient increase in the number of internal current-producing cells (choanocytes) to provide adequate flow. Syconoid sponges have partially overcome this problem by folding their body wall to increase the surface area of the choanocyte layer and by reducing the atrium to lessen the volume of circulated water. Thus, a much greater size is possible for this type sponge. In the even more advanced leuconoid sponges, the highest degree of folding takes place, choanocytes no longer line the atrium but are confined to evaginations, and the atrium has been reduced to water channels leading to the osculum.

Deep-ocean sponges were among the most abundant and diverse animals observed on the shipwreck. The hard objects of the shipwreck (e.g. coal, ironworks, leather, and timbers) provided abundant location for these and other sessile creatures to become permanently affixed. Two classes of sponges were identified: Demospongiae (horny sponges) and Hexactinellida (glass sponges), with the latter dominating. The horny sponges tended to encrust firm objects or to form massive plate-like bodies, while the more diverse glass sponges (Figs. 67, 83, 84, 85) had a more definite, often ornately structured body shape (e.g., *Farrea occa, Aphrocallistes beatrix, Caulocalyx tenera, Rhabdodictym* sp., and *Calyptorete* sp.). One of the *Farrea* specimens collected from a collapsed beam appeared to be a new species (Figs. 86, 87) and another specimen in the family Aulocalycidae (Fig. 88) was likely to be a new genus. Investigations of these and other sponge specimens collected at the site are being continued by Dr. Henry M. Reiswig at the Redpath Museum of McGill University, Montreal, Quebec. Dr. Reiswig characterized the site as rich and diverse in its sponge fauna, perhaps one or two orders of magnitude greater than the surrounding area because of the hard surfaces for attachment and the possible nutrition provided by the decaying wood from the shipwreck.

Class Demospongiae

This class contains some 90% of all sponge species and most of the familiar shallow-water forms. Demosponges range in distribution from shallow water to great depths

FIGURE 83. Dense colonization of hexactinellid sponges and gorgonian corals on a boiler. The feather-like sponges (center foreground and lower right) are members of the genus *Farrea*. The large white sponges (lower center and right center) belong to the genus *Calyptorete*, as do many of the larger sponges in the background. The large horn-shaped white sponge (top center) is the species *Caulocalyx tenera*. The delicate plumes in the background (upper left) are gorgonian corals (*Chrysogorgia*). A few white galatheid crabs (*Munidopsis*) are crawling over the corroded surface of the boiler. Large rope-like strands of iron rusticles are flowing down the boiler (right foreground).

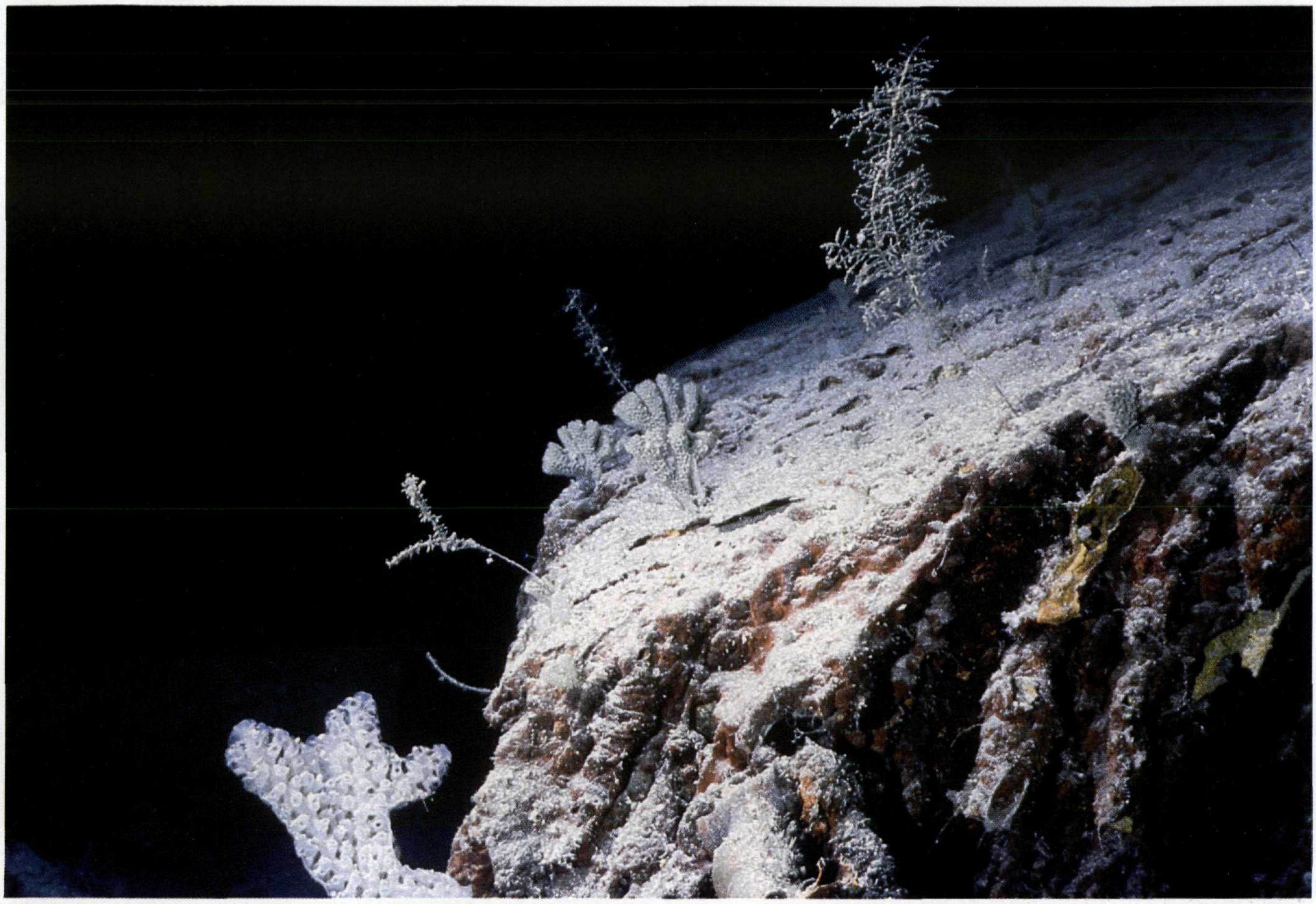


FIGURE 84. Corroding iron tank colonized by hexactinellid sponges and gorgonian corals on the shipwreck of the SS *Central America*. The numerous greenish-gray, branching sponges (center) are members of the genus *Rhabdodictym*. The porous appearance of many of the larger ones of this type indicate that the living "tissue" has died and only their silicate skeleton remains. The larger white sponge (lower left) is a living member of the genus *Calyptorete*. The tall, branching animal (upper right)is a gorgonian coral (*Thouarella crenulata*). Shorter axial stalks of dead gorgonian corals can be seen scattered over the top and left side of the tank. On the front face of the tank, large rope-like strands of iron rusticles flow downward. At the right, the reddish-brown surface of one of these rust features has been removed exposing a yellowish iron oxide (limonite).

and frequently have brilliant coloration. The skeleton of this class is variable, consisting of siliceous spicules, or spongin fibers, or a combination. All demosponges have a leuconoid structure and all types of growth patterns are exhibited. Deep-water demosponges often have long basal stalks which are anchored to soft seafloors or they encrust hard surfaces where such material is present.

Four families of demosponges were represented at the site: Axinellidae, Haliclonidae, Esperiopsidae, and Hymedesmiidae (Appendix A). Most of these sponges were small, forming encrustations on the ship's timbers and other materials. However, two distinctive demosponges were recovered from a leather-bound trunk that once belonged to Oregon merchant, John Dement (Fig. 89). The first, *Phakellia* (Axinellidae), had a puffy form with supporting spicules (megascleres) enclosed in spongin fibers. Non-supporting spicules (microscleres) were absent. The other, *Haliclona* (Haliclonidae), had a large fan-shaped form and was known to produce free-swimming, flagellated larvae (Hartman 1982) that quickly settle and attach themselves to hard surfaces. This strategy appeared beneficial in colonizing the timbers of the shipwreck.

Dr. Reiswig also discovered an unknown genus in the family Esperiopsidae. In general, the megascleres in this family are uniform in size and shape throughout this sponge. Another encrusting sponge, *Hymedesmia* (Hymedesmiidae) possessed a skeleton composed mostly of monactinal megascleres (spicules with two dissimilar ends) to which accessory diactinal megascleres (spicules with two similar ends) are attached. This small demosponge was recovered from a quillworm tube that also contained a bryozoan scale. This observation appeared to be a depth record for the family which normally inhabits the seabed at depths less than 150 m (Hartman 1982). With the exception of *Phakellia* and *Haliclona*, demosponges did not form a showy component of the megafauna on the shipwreck but they probably encrusted many hard surfaces.

Class Hexactinellida

Members of this class derive their name from the six-pointed (hexaxon) spicules that form their skeletons (Fig. 90). The spicules are often fused to form a lattice-like skeleton built of long siliceous fibers which gives this group a peculiar structure different from all others.

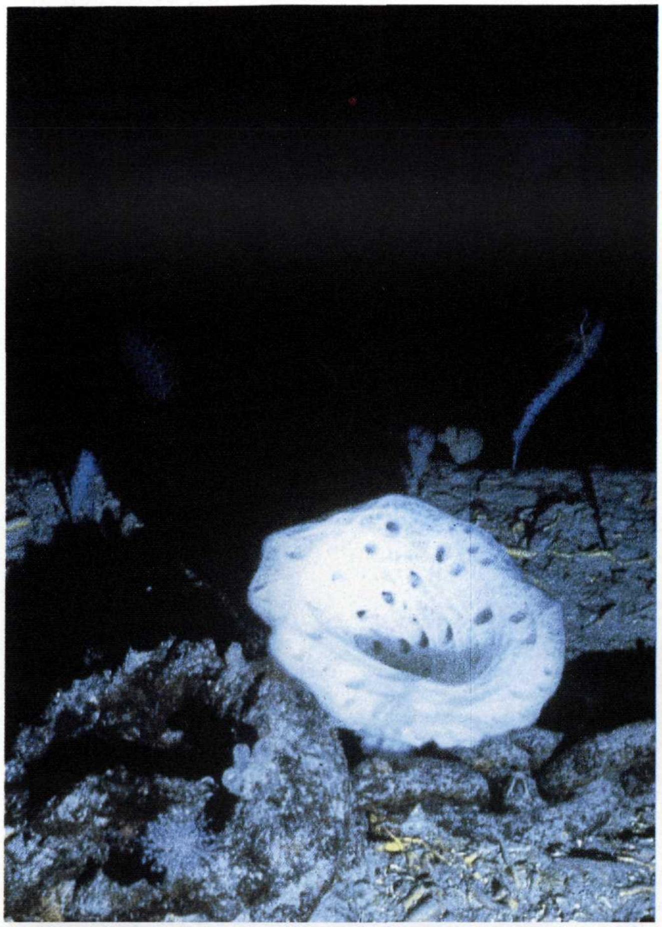


FIGURE 85. Delicate hexactinellid sponge (*Caulocalyx tenera*) growing on an iron tank. The top of a water tank is littered with tubes from wood-boring bivalves in the family Pholadidae. The feather-like structures in the background are another species of hexactinellid sponge in the genus *Farrea*. Two plume-like corals in the genus *Chrysogorgia* are growing to the lower left of the large white sponge. At lower center, a reddish-purple soft coral (*Anthomastus agassizi*) grows attached to the ship's anchor chain which is draped across the tank.

Their bodies consist of a trabecular net in which flagellated chambers are located that resemble the canals of syconoid sponges (Bayer and Owre 1968). Glass sponges are the most symmetrical group of sponges and often form cup-like or vase-like shapes. Some species are adapted to living on soft bottoms. Basal tufts or spicule fibers implanted in sand or sediment ooze serve as an anchor. Hexactinellids are chiefly deep-water sponges. They were the dominant sponges on the shipwreck site and one of the most abundant animal groups on the wreck. On the hard materials of the shipwreck, sponges were fastened by basal extensions of their bodies that were supported by long spicules. Some of the most beautiful and delicate sponges in the sea (e.g., *Euplectella* and *Farrea*) are in this group. Only one species, *Euplectella jovis*, was observed growing on the sediment ooze at Site H (Fig. 59), all others were attached to parts of the shipwreck or other animals. When these sponges die, their glassy skeletons remain erect for many years.

Nine families of glass sponges were represented on the shipwreck site: Farreidae, Euretidae, Aulocalycidae, Craticulariidae, Aphrocallistidae, Leucopsacadidae, Caulophacidae, Euplectellidae, and Rossellidae (Appendix A). The first five families are within the order Hexactinosida and are characterized by a rigid skeleton resulting from the fusion of hexactines (spicules with six rays), whereas the latter four families are in the order Lyssacinosida and typically have large spicules that are free in the body.

Dr. Henry M. Reiswig, in collaboration with Dr. Dorte Mehl, Institute for Paleontology, Freie University, Berlin, undertook a study of the largest sponge colony discovered on the shipwreck site, originally identified as *Leptophragmella choanoides*. On decaying timbers, the blanket-like form of this sponge was measured to cover a 1-m^2 area. Its gentle folds resembled the stacked egg-shell design of the Sydney Opera House (Fig. 91). From a live sample of this sponge, they were able to show by analysis of skeletal features that *Leptophragmella* was identical to the earlier described genus *Chonelasma*, effectively making the former name invalid (Reiswig and Mehl 1994). Electron microscopy of the living "tissues" showed that *C. choanoides* possessed distinctive perforated septal partitions (plugs). This sponge was found to have continuous networks of protoplasm with special plugs partially separating the networks into regions. Reiswig and Mehl interpreted the plugs to be a primitive method of developing specialization of those regions of living tissue. They postulated that ancestral stocks with these characters may have given rise to descendants with complete separation of specialized cells, a pattern basic to all other animals. Thus, rather than being an evolutionary dead end, this group of sponges may be an important key to the earliest stages of animal evolution.

The longevity of hexactinellid sponges appeared to be at least several years but the growth rate was very slow. Individual sponges, particularly of the genera *Farrea*, *Caulocalyx*, *Rhabdodictym*, and *Chonelasma*, initially photographed in 1988, showed no discernible change by 1991. The relative independence of sponge cells gives rise to remarkable powers of regeneration. To test the rate of regeneration in the deep ocean, in September 1989 approximately 20 cm^2 was removed from a large mat of *Chonelasma choanoides*. When reexamined in 1990 and 1991, no new growth was noted where the segment had been removed.

Deep-sea sponges are rarely eaten because their flesh contains noxious chemicals which render it unattractive to other animals (Bayer and Owre 1968). Certain crustaceans and polychaetes live commensally with hexactinellids, using the sponges for protection as well as camouflage. This symbiotic relationship was well illustrated on the shipwreck by the hexactinellid *Chonelasma choanoides* and the small galatheid crab *Munida microphthalma*. Under the lights of the submersible, this white sponge appeared brilliant, almost blue-white, in color. The images received on the control room monitors showed the delicate galatheid crab to be similarly white and almost invisible against the sponge background (Fig. 92). At a nearby location, a delicate caridean shrimp was found embedded in the folds of another glass sponge, *Calyptorete*, and was vigorously

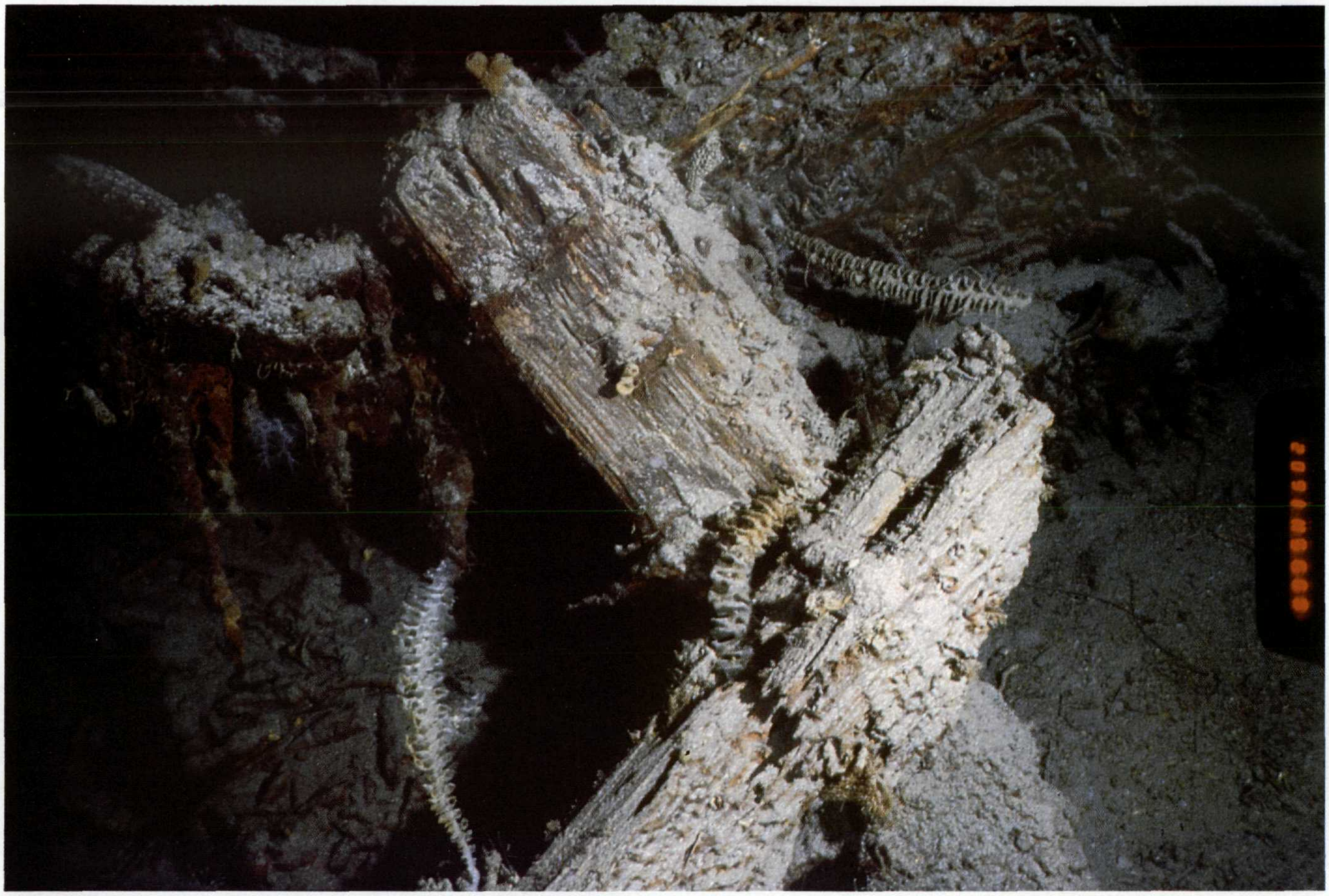


FIGURE 86. Collapsed beams of the *Central America* form an "X" at the edge of the shipwreck. The beams are colonized by hexactinellid sponges. The three large plumes are an undescribed species in the genus *Farrea*. The small, brown, ovoid sponge at the top of the higher beam is *Rhabdodictym delicatum*.

feeding on particles trapped by its net-like appendage. Bergquist (1978) has shown that excurrent water from the sponge satisfies the nutritional and respiratory needs of the commensal animal and that their larvae may also be guided to the host sponge by chemical and hydrodynamic information in the excurrent water.

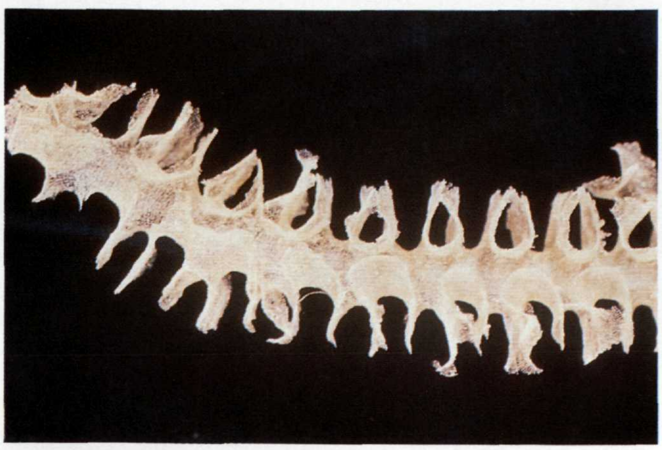


FIGURE 87. Skeleton of a hexactinellid sponge recovered from the shipwreck. The skeleton is composed entirely of six-rayed glass spicules (see Fig. 90) and belongs to an undescribed species in the genus *Farrea*. Photograph courtesy of Dr. Ronald B. Toll.

Because of the noxious chemicals produced by deep-sea sponges, they are excellent subjects for biomedical research and are sought by scientists working to isolate natural products which may have pharmaceutical value. Deep-sea animals exhibit a number of disease fighting factors, including: 1) anti-viral, 2) anti-fungal, 3) anti-tumor, 4) anti-inflammatory, and 5) immunomodulatory (able to stimulate or suppress immune system response). In September 1989, samples of *Farrea* and *Chonelasma* were obtained from the wreck site and air freighted to Dr. D. John Faulkner, marine biochemist, Scripps Institution of Oceanography. Dr. Faulkner screened these animals for possible anti-inflammatory agents. Initial results were negative but an unusual inorganic silicon compound was detected. Additional deep-sea samples were collected for Drs. John M. Cassady and David K. Ho, College of Pharmacy, The Ohio State University, for testing in their anti-tumor and cancer research programs. A specimen from the undescribed genus in the family Aulocalycidae has been delivered to these researchers for analysis. Results of their testing have not yet been released.

The procurement of food and elimination of waste by sponges depends on the current of water flowing through their bodies. A demosponge 10 cm high and 1 cm in diameter is capable of pumping water through

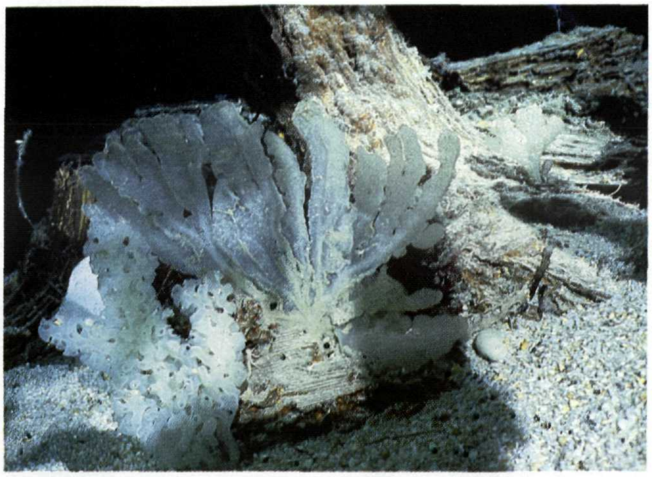


FIGURE 88. Hexactinellid sponges colonize a hanging knee on the shipwreck. The branching tubular sponge at left is an undescribed species in the genus *Farrea*. The large fan-like sponge at center is believed to be a new genus in the family Aulocalycidae. The smaller branching sponge at upper right is a member of the genus *Rhabdodictym*. All three sponges appear to be healthy because their internal skeletons have a complete protoplasmic covering. The sediment upon which the knee rests is a coarse pteropod ooze.

its body at a rate of 22.5 l/day (Barnes 1987). A collar at the base of the choanocyte is composed of a microvillar mesh which traps food particles and is about the same dimensions in both demosponges and hexactinellid sponges (Reiswig 1990). Sponges feed on extremely fine particle material; no matter how massive the sponge, its feeding is restricted to food no larger than can pass through its pore and be engulfed by a single cell. Studies on subtropical species have demonstrated that 80% of the filtered organic matter consumed by these sponges is too small to be resolved with an ordinary microscope and that the other 20% consists of bacteria and nanno-plankton (Reiswig 1971).

Few animals prey on sponges but some are eaten by gastropods, principally nudibranchs, and by certain sea stars. Their sharp spicules render them inedible to most animals. Sponges produce metabolites that prevent other organisms from settling on them or deter potential browsing predators. Many sponges have a very disagreeable taste and odor which also offers a degree of protection from predators. Some galatheid crabs break off pieces of sponges and place them on their carapace where the sponges continue to grow and camouflage the crab, in a manner similar to shallow water decorator crabs (MacGinitie and MacGinitie 1968). Specimens of *Munidopsis bermudezi* recovered from the site had a particularly "fuzzy" appearance, possibly as a result of this practice.

Asexual reproduction in sponges is primarily by vegetative means; a bud forms on the parent, and may either remain attached or break off to drift and settle at a new place of attachment. Morphological evidence in the images from the shipwreck site suggested that some hexactinellids formed either buds or inflation lobes, including *Calyptorete*, *Rhabdodictym*, and *Aphrocallistes*. The massive lobes of *Chonelasma*, which grew by vegetative means on the shipwreck timbers, is one of the largest deep-ocean sponges on record (Reiswig and Mehl 1994).

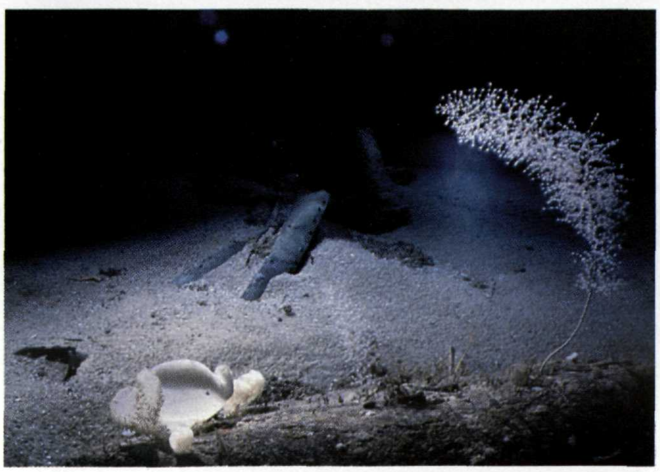


FIGURE 89. Leather trunk in the debris field that surrounds the wreck of the *Central America* (see Fig. 147). The trunk is colonized by a plumy golden coral (*Chrysogorgia* new species) and two demosponges: *Haliclona* sp. (rough surface) and *Phakellia* sp. (smooth surface).

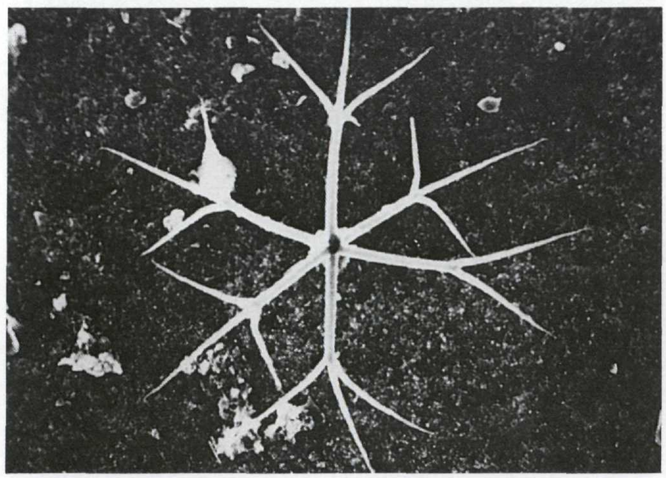


FIGURE 90. A six-rayed hexactinellid sponge spicule. This spicule was extracted from an undescribed species in the genus *Farrea*, collected at the shipwreck (see Figs. 86, 87). Photomicrograph courtesy of Dr. Henry M. Reiswig.

Sexual reproduction by dioecious or hermaphroditic individuals is much more common. In some, both egg and sperm cells are shed into seawater where fertilization by fusion takes place. But in most sponges only sperm cells are shed and then carried into another individual in its water current where internal fertilization occurs (Reiswig 1970). Thus, the majority of sponges are viviparous, with development of the larval stage taking place within the body of the parent. This has been demonstrated in the hexactinellid genus *Farrea* (Hyman 1940). The larva, known as a parenchymula, is then released and has a brief, free-swimming existence (1 to 2 days). The larva has flagellated cells covering its body and spicules are often present. Following settling

FIGURE 91. "Sydney Opera House" sponge (*Chonelasma choanoides*) blankets the timber on the *Central America* shipwreck. This is one of the largest known glass sponge colonies in the North Atlantic Ocean. An orange brisingid sea star (*Brisinga cricophora*) is at left.

and attachment, the larva undergoes an internal reorganization and the formation of choanocytes. The rapid settlement of sponge larvae appeared to be a significant advantage in the deep ocean where suitable habitat, such as the timbers of a shipwreck, were limited in areal extent.

FIGURE 92. Hexactinellid sponge (*Chonelasma choanoides*) (Sydney Opera House sponge) on timbers of the *Central America*, showing a symbiotic galatheid crab on the sponge colony.

PHYLUM CNIDARIA

Also known as Coelenterata, this phylum includes familiar forms such as hydroids, jellyfish, corals, and sea anemones. Each of these groups had representatives on the shipwreck of the SS *Central America*. All cnidarians possess two basic structures typical of multicellular animals that are not found in sponges: a gastrovascular cavity and a mouth. A circle of tentacles surrounds the mouth to aid in the capture and ingestion of food, and the body plan is based on radial symmetry. Two markedly different structural types are exhibited by cnidarians: a sessile polyp and a free-swimming medusa. All cnidarians possess unique, specialized cells (cnidocytes) that contain small organelles that are capable of eversion, including stinging structures (nematocysts).

Gorgonian corals and sea anemones were among the dominant members of the benthic assemblage on the shipwreck. But, several other groups were represented by a few species. These included the small hydroids, siphonophores, nausithoid jellyfish, alcyonacean (soft) corals, scleractinian (stony) corals, and antipatharian (black) corals.

Class Hydrozoa

Hydrozoans are small animals with most species having both polyp and medusa forms. Polyps are the column-shaped parts of hydrozoan colonies that are generally sedentary and attached to firm substrate, whereas medusae are free-swimming umbrella-shaped forms. Hydrozoans are inconspicuous members of the marine community but they grew profusely on hard surfaces of the shipwreck. Elongated polyps of hydrozoans were observed attached to most iron surfaces. A particularly good example of a hydrozoan colony, *Tubularia*, was photographed on the ship's anchor chain which had fallen over an iron tank (Fig. 70).

Colonies were typically anchored by a root-like stolon (hydrorhiza) which spread horizontally over the substratum. Single, upright polyps or branches of polyps arose from the stolon. Different growth and budding patterns resulted in branches that were aborescent (tree-like) or pinnate (feather-like). *Acryptolaria conferta* and *Pennaria*, respectively, represented these forms on the shipwreck. Most hydroid colonies were 1 to 10 cm high and drab in color. The majority of hydroids, such as *Tubularia*, do not produce a free-swimming medusa. Instead, the medusa is attached to the parent hydroid but is a sexually reproducing individual. In *Tubularia*, medusae are formed on gastrozooids where they remain and are known as gonophores. Fertilization takes place in these structures and development of the embryo takes place through the planula stage, culminating in the release of an actinula larva. This larva, which looks like a stubby hydra, eventually settles to the bottom, moves about, and finally develops into a new hydroid colony (Bayer and Owre 1968).

Members of the order Siphonophora exist largely as epipelagic colonies but a few are known to descend to deep-sea levels (Marshall 1979). They exhibit a high degree of polymorphism within interconnected complexes of medusoid and polypoid elements, each serving a separate function, but integrated as a colonial organism. A bizarre-looking form, *Pterophysa grandis*, was occasionally recovered from the "umbilical" cable of the submersible, *Nemo*. The depths at which the several-meter-long colonies became attached to the cable were unknown. Agassiz (1888) also reported collecting 10-m long colonies of this species from the dredge-wire of the steamer *Blake* while sampling in the Caribbean Sea. He inferred that this species was a deep-sea siphonophore.

Class Scyphozoa

Cnidarians of this class are commonly referred to as jellyfish. The medusa is the dominant and conspicuous phase in the life cycle, making these animals largely pelagic. The polypoid form (scyphistoma) is restricted to a small, larval stage. Most scyphozoan medusae range from 2 to 40 cm across the bell. Many species have four or eight oral arms which aid in the capture and ingestion of prey. Deep-sea scyphozoans are probably suspension feeders, trapping plankton or organic debris in mucus on the bell surface. Cilia then sweep the food particles to the bell margin where they are scraped off by the oral arms. Ciliated grooves on the oral arms carry the food to the mouth.

The order Coronatae is distinguished from other scyphozoans by the morphology of the medusa bell which has a deep, encircling groove or constriction (coronal groove) extending around the exumbrella. Many deep-sea species are found in this order. Some coronate scyphozoans have nearly eliminated the need for medusae. One such genus, *Stephanoscyphus*, has branching colonial polyps with a supportive skeletal tube and a much reduced medusoid stage. *Stephanoscyphus* produces a small, transparent medusa that develops ripe eggs during or immediately after polydisc strobilation, a process where the immature medusae are stacked up like saucers on the oral end of the scyphistoma (Werner 1973). This species commonly permeates the interior spaces of sponges or grows attached to inanimate objects (Hyman 1940). Small dark brown colonies of *Stephanoscyphus* polyps were observed on shipwreck and specimens were discovered by Timothy E. Coffer, Department of Invertebrate Zoology, National Museum of Natural History, while inspecting a sediment-water interface sample collected at the site in September 1989.

Swimming motion is brought about by a band of powerful, circular muscle fibers on the underside of the bell which create pulsations. Scyphomedusae, such as *Atolla*, typically drifted with the currents a few meters above the bottom but others were rapid swimmers particularly when distressed. In August 1991, a 4-armed scyphomedusa was partially covered with debris during a recovery operation and its arms were trapped. The bell pulsated vigorously for several minutes until the submersible operator came to the animal's rescue and cleared away the debris. Once free, the animal continued to pulsate and immediately rose in a near vertical direction for several meters.

Most scyphozoans are dioecious with eggs or sperm passing out through the mouth for fertilization in the sea. In some species, the eggs become lodged in pits in the oral arms. This brood chamber is the site of fertilization and development to a ciliated planula larval stage. After a brief, free-swimming existence, the planula settles to the bottom, becomes attached, and develops into a small polypoid larva called a scyphistoma. In some scyphozoans, including *Stephanoscyphus*, medusa formation is accomplished in a series of fissions (strobilation) of the oral end of the scyphistoma.

Class Anthozoa

Anthozoans are either solitary or colonial, polypoid cnidarians in which the medusoid stage is lacking. Members of this class include familiar forms such as sea anemones, corals, and sea fans. A distinguishing feature of this class is a gastrovascular cavity that is divided by longitudinal mesenteries, or septa, into radiating compartments. Colonies and solitary individuals are both common in this class and both types were commonly observed on the shipwreck.

Anthozoa is divided into two subclasses: Alcyonaria (or Octocorallia) and Zoantharia (or Hexacorallia). The octocorals include common marine forms such as sea pens and sea fans. All octocorals have eight pinnate tentacles, eight complete mesenteries, and a single oral groove (siphonoglyph). Representatives of three orders of this subclass were found on the shipwreck site: 1) Pennatulacea (sea pens), 2) Alcyonacea (soft corals), and

3) Gorgonacea (gorgonian corals). Gorgonians were a dominant group on the site and the other two were only occasionally observed. The hexacorals include four orders which were observed on the shipwreck site, the first two were common, the third was relatively rare, and the last was somewhat doubtful: 1) Actiniaria (sea anemones), 2) Scleractinia (stony corals), 3) Antipatharia (black corals), and 4) Zoanthidea. The radial symmetry of hexacorals is generally based on a plan of six. Mesentaries and tentacles are typically in multiples of six, with 12 being the most common—never just eight. This subclass is much more heterogeneous than the octocorals.

Most anthozoans are dioecious and/or hermaphroditic. Sperm and egg cells are either shed directly into seawater where fertilization takes place or the eggs are held internally where fertilization takes place via water currents. In the latter case, development takes place up to the planula larva stage before a free-swimming larva is released and eventually settles to take up a sessile existence.

Class Anthozoa: Subclass Alcyonaria

Order Pennatulacea. Sea pens are more or less fleshy colonies with very elongated bodies formed of a primary axial polyp and of numerous secondary polyps which spring laterally from the primary one. The body is divided into a lower stalk (peduncle) and an upper region of secondary polyps (rachis). The base of the stalk lacks any special means of attachment and is simply an enlarged bulb thrust into the soft bottom. Sea pens possess a skeleton of calcareous spicules for support. Abyssal sea pens (e.g., *Umbellula* and *Pennatula*) have a characteristic pinwheel-shaped rachis formed by a whorl of secondary polyps. Such octocorals have been photographed as deep as 5,000 m on the Atlantic abyssal plain (Barnes 1987). Octocorals resembling this design were infrequently observed on the soft sediment ooze surrounding the site but none were found on the shipwreck.

Order Alcyonacea. Members of this order are known as soft corals or leather corals. In contrast to other octocorals, the polyps of soft corals are embedded in a gelatinous, rubbery mass (coenenchyme). They have skeletons of unconnected, calcareous spicules. The fleshy colonies are generally irregular in shape, some are encrusting, some are massive or mushroom-shaped with numerous protruding polyps, and others are branched into stout, blunt lobes, or fingers. Only a few small colonies of this order were observed and photographed on the shipwreck. Typically, they occurred on elevated, hard surfaces (e.g., ironworks and collapsed timbers) and they formed sessile colonies with finger-like projections. Although only a few centimeters high, colonies of *Anthomastus agassizi* were striking in their shades of pink and violet colors against the rather drab background (Figs. 63, 85), while *Neospongodes agassizi* was colorless and nearly transparent (Fig. 60).

Soft corals are typically littoral animals but a few inhabit deeper water to at least 3,000 m. Deep-sea forms living in soft sediment are anchored to the bottom by root-like tufts while those that lived on the shipwreck were fastened to hard objects by basal plates or stolons. Shallow-water species, being subject to waves, tend to be fleshy and flexible while deeper forms are more erect, branching, and have greater spiculation (Hyman 1940).

Order Gorgonacea. Sometimes called horny corals, these graceful forms include the sea whips, sea feathers, and sea fans which are common features of tropical reefs. However, the hard metal surfaces, coal piles, and even the timbers of the *Central America* wreck formed suitable substrates for these animals some 2 km below the ocean surface. One family, Chrysogorgiidae (golden corals) is almost entirely confined to the deep ocean and is extremely rare. The genus, *Chrysogorgia*, was a conspicuous member of the biological community on the wreck (Figs. 67, 71, 72, 93). Small spicules held within the polyps of these animals are thin, oval plates. This suggests to some researchers that the family is the most primitive of all gorgonians; others believe that this feature and other characters may be associated with life in the slow, uniform currents of deep water and therefore a sign of special adaptation rather than a primitive feature (Hickson 1924). Recent work by Dr. Frederick M. Bayer, National Museum of Natural History, Smithsonian Institution, revealed the spicule design (Fig. 94) and the whorl configuration of specimens of *Chrysogorgia* retrieved from the SS *Central America* were quite dissimilar from those collected by early expeditions and most likely represented a new and undescribed species. Two other gorgonian species, *Thouarella crenulata* (Fig. 84) and *Paragorgia johnsoni*, were seen less frequently on the shipwreck.

The body of most gorgonian corals contains a central axial rod composed of an organic substance (gorgonin). The axial rod is commonly impregnated with calcium carbonate. The color of these calcareous skeletal components imparts the yellow, orange, or lavender shade of some gorgonians. Members of the family Chrysogorgiidae have a yellowish metallic luster, hence the name golden coral. In some species, calcified sections alternate with noncalcified sections, giving the rod a jointed appearance. Around the rod is a cylinder, or rind, of connective tissue (coenenchyme), which consists of a thick mass of mesoglea into which the polyps are set. The rind contains tubes running to the feeding polyps. Numerous calcareous spicules of various shapes provide support for the polyps. The polyps are rather small but have the typical features of an octocoral.

The majority of gorgonian colonies on the shipwreck appeared as erect, plant-like growths of slender, branching stems from an elongated main trunk fastened to the substratum by a basal plate (Fig. 93). Some colonies of *Chrysogorgia* exceeded 30 cm in height. Gorgonians inhabiting quiet or deeper water tend to branch freely in all directions yielding a bushy shape. This was the case with the whorl branching exhibited in over 100 specimens of *Chrysogorgia* observed on the site.

Gorgonian corals may feed on zooplankton like stony corals but gorgonians possess small numbers of cnidocytes which suggests that they feed on organic particles smaller than zooplankters (Lasker 1981). Video images showed circulating water currents around the polyps,

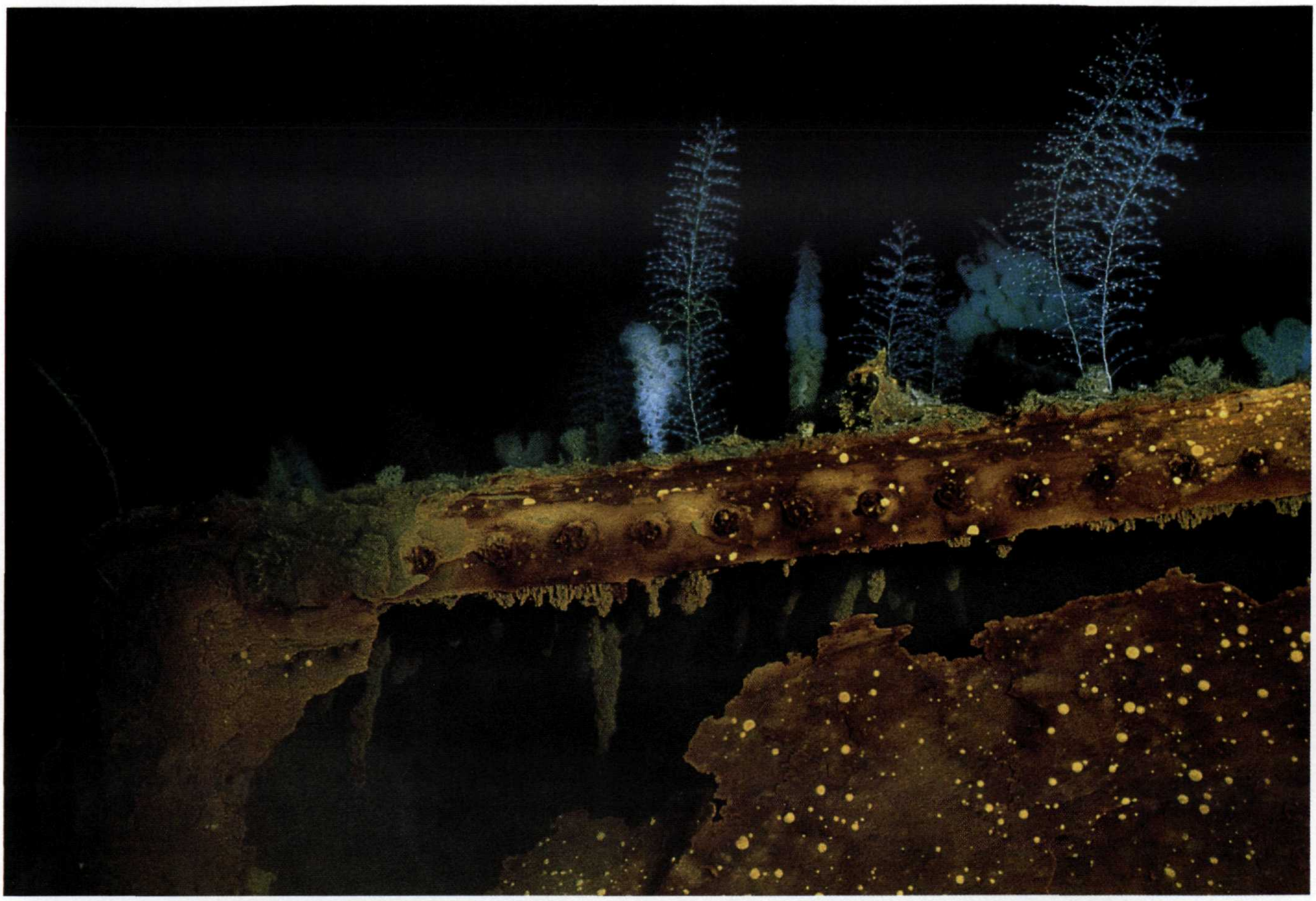


FIGURE 93. An iron water tank on the shipwreck site provides a hard place for attachment for a community of gorgonian corals and hexactinellid sponges. Several golden corals (*Chrysogorgia* new species) and numerous glass sponges colonize the top of the tank: *Farrea* sp. (tall, plume-like) and *Rhabdodictym* sp. (short, branched).

confirming that *Chrysogorgia* utilized a suspension feeding strategy.

As a result of their sessile habits and firmness, gorgonian corals frequently serve as a substrate for a variety of other sessile and crawling animals (e.g., sponges, hydrozoans, bryozoans, brachiopods, sabellid worms, colonial tunicates, barnacles, bivalves, and gastropods), at times to the detriment of the hosts. On the shipwreck site, the comatulid crinoid *Caryometra* typically perched near the top of a living or dead axial rod of *Chrysogorgia*. The pedunculate barnacle *Megelasma* was also a common symbiotic animal attached to colonies of *Chrysogorgia*. This attachment appeared to take the form of a net (somewhat like a spider web) composed of filamentous, thoracic appendages.

Class Anthozoa: Subclass Zoantharia

Order Actiniaria. This order comprises the sea anemones. Individuals are solitary polyps that are considerably larger than the polyps of hydrozoans, most ranging from 2 to 10 cm in length and from 1 to 5 cm in diameter. Sea anemones are often brightly colored, being white, green, orange, red, purple, or a combination of these colors. They typically live attached to submerged rocks, shell material, and timbers. Some form burrows in the sand or mud while others are commensal on other animals, especially the shells of molluscs. Sea anemones were observed on all of these habitats at the shipwreck site except for soft sediment.

The basic body of the sea anemone is formed by a heavy column which may be smooth, warty, or bear tentacle-like outgrowths. The base (aboral end) of the column is flattened into a pedal disc for attachment. At the oral end, the column flares slightly to form an oral disc which bears from eight to several hundred hollow tentacles. In some species the oral disc is drawn out into lobes. When sea anemones were disturbed on the shipwreck, they contracted by pulling the upper surface of the column over the oral disc. A slit-shaped mouth is located in the center of the disc which bears at one or both ends of the slit a ciliated groove (siphonoglyph). The groove facilitates the circulation of water into the gastrovascular cavity which is necessary to maintain a fluid (hydrostatic) skeleton and for gas exchange. As in all anthozoans, the cavity is partitioned by longitudinal, radiating mesenteries that usually occur in multiples of 12.

Dr. Daphne G. Fautin, Department of Systematics and Ecology, University of Kansas, examined specimens and videotape and Dr. Barbara Hecker, Lamont-Doherty Earth Observatory, Columbia University, studied photographs of sea anemones from the shipwreck site.

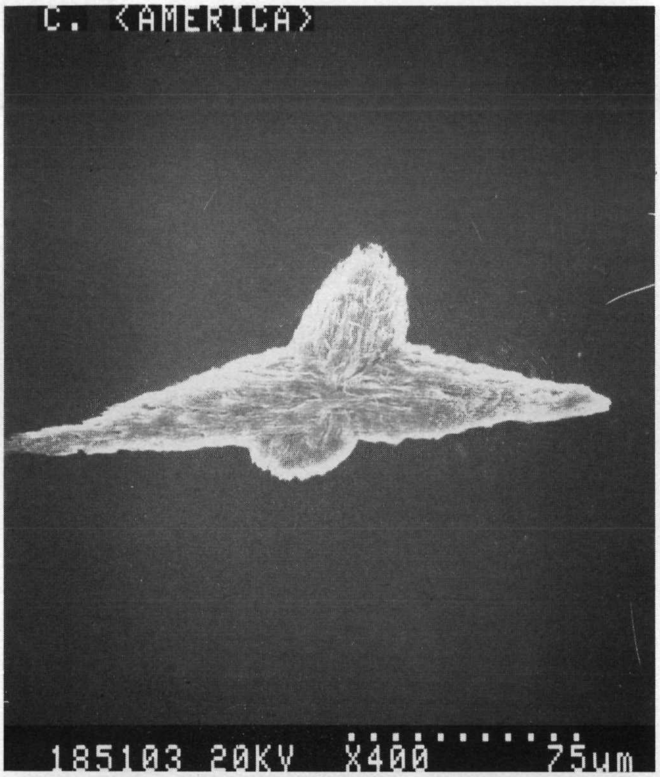


FIGURE 94. Scanning electron microscope photomicrograph of the spicule from the polyp of *Chrysogorgia* new species. Magnification: 400X. Photomicrograph courtesy of Dr. Frederick M. Bayer.

They have identified four families of actinarians which inhabited the site: Actinernidae, Actinoscyphiidae, Actinostolidae, and Hormathiidae. Two species of actinernids were believed to be present, *Actinernus michaelsarsi* and *A. nobilis.* These anemones had a thick, smooth column and numerous tentacles at the margin. A white and purple specimen was collected along with it's substrate, a baked clay brick (Artifact No. 29333).

One actinoscyphiid genus, *Actinoscyphia*, was tentatively identified from sea-bottom photographs. The body wall was thick and gelatinous in texture but the base was small. The tentacles were marginal and the expanded bilobed oral disc somewhat resembled a Venus flytrap. The body was a distinct canary-yellow color. Some of the best images of this sea anemone were obtained while scanning a leather-bound trunk.

Actinostolids were among the most showy anemones observed on the site. A brilliant orange form, *Paractinostola*, had a double row of fleshy tentacles emanating from a knobby, white body column (Fig. 95). The oral disc was lobed and capable of enclosing the tentacles when disturbed. This large species, over 10 cm across the oral disc, was relatively abundant on the site, colonizing collapsed timbers and leather trunks. Dr. Fautin found that a recovered specimen had mesenteries arranged according to the "*Actinostola* rule" (Dunn 1982). Nematocyst measurements for this specimen differ from published accounts for known species within the genus *Paractinostola;* thus the specimen recovered from the shipwreck may represent a new species.

Hormathiids at the site were small anemones of a golden-brown to reddish-brown color. Their body column was covered with a cuticle and they possessed numerous thin tentacles. One species *Chondrophellia coronata* was commonly observed among stacks of gold coins. Another member of this family, similar in appearance to *Paracalliactis*, was found attached to a gastropod shell which housed a hermit crab.

As noted above, some of the most brilliantly colored animals on the shipwreck of the *Central America* were anemones, such as *Paractinostola* and *Actinoscyphia.* Red and orange colored animals presumably reflect very little natural background light in the deep ocean and thus should be difficult to see (Marshall 1979). Notwithstanding, colors of this brilliance were unexpected at a depth of 2,200 m where perhaps no light had ever entered until *Nemo* illuminated the ocean floor. These anemones and numerous other less showy yellow and golden-brown forms, had attached their basal discs to the timbers and lumps of coal of the wreck. These animals were large, solitary polyps. Although sea anemones are essentially sessile animals, many are able to change location by slowly gliding on their pedal disc, crawling on the side of their column or even walking on their tentacles. A disturbed individual, *Paractinostola*, was observed using a combination of the latter two techniques. The usual feeding movements, opening and closing of the oral disc were mostly slow but when disturbed contraction was rapid. Most of the deep-sea forms appeared to open their tentacles widely to collect bits of settling organic matter rather than catch active prey. Planktonic organisms and debris were observed on the tentacles and on the surface of the column. Cilia on the tentacles beat toward the tips carrying particles in that direction. The tentacles tips were then bent inward to deposit the food in the mouth. Cilia on the column beat directly toward the oral disc.

Digestive enzymatic activity from the presence of amylase has been correlated in actiniarian sea anemones with seasonal abundance of microalgae in the environment, indicating that phytoplankton is important in the diet of these omnivores (Van-Praet 1982). High amylase activity found in *Paracalliactis stephensoni* collected at a depth of 2,000 m suggests that this deep-sea anemone feeds on the phytoplankters settling out of the water column or collected from the sediment surface (Van-Praet 1981). Much lower amylase activities were noted in *Actinauge* collected at 4,000 to 5,000 m, perhaps because the phytoplankton sinking to these depths consists largely of diatoms which do not store the starches that would induce amylase activity (Shick 1991).

Asexual reproduction by splitting of the pedal disc or by longitudinal fission is common in sea anemones. However, most sea anemones are hermaphroditic with individuals producing only one sex of gamete during any one reproductive period. Eggs are commonly fertilized in the gastrovascular cavity with development taking place in the mesenterial chambers. Fertilization can also occur outside the body in seawater. The resulting planula larva is ciliated and free swimming but has no tentacles. Eventually the larva settles, attaches, and forms tentacles. Photographs of the same individuals

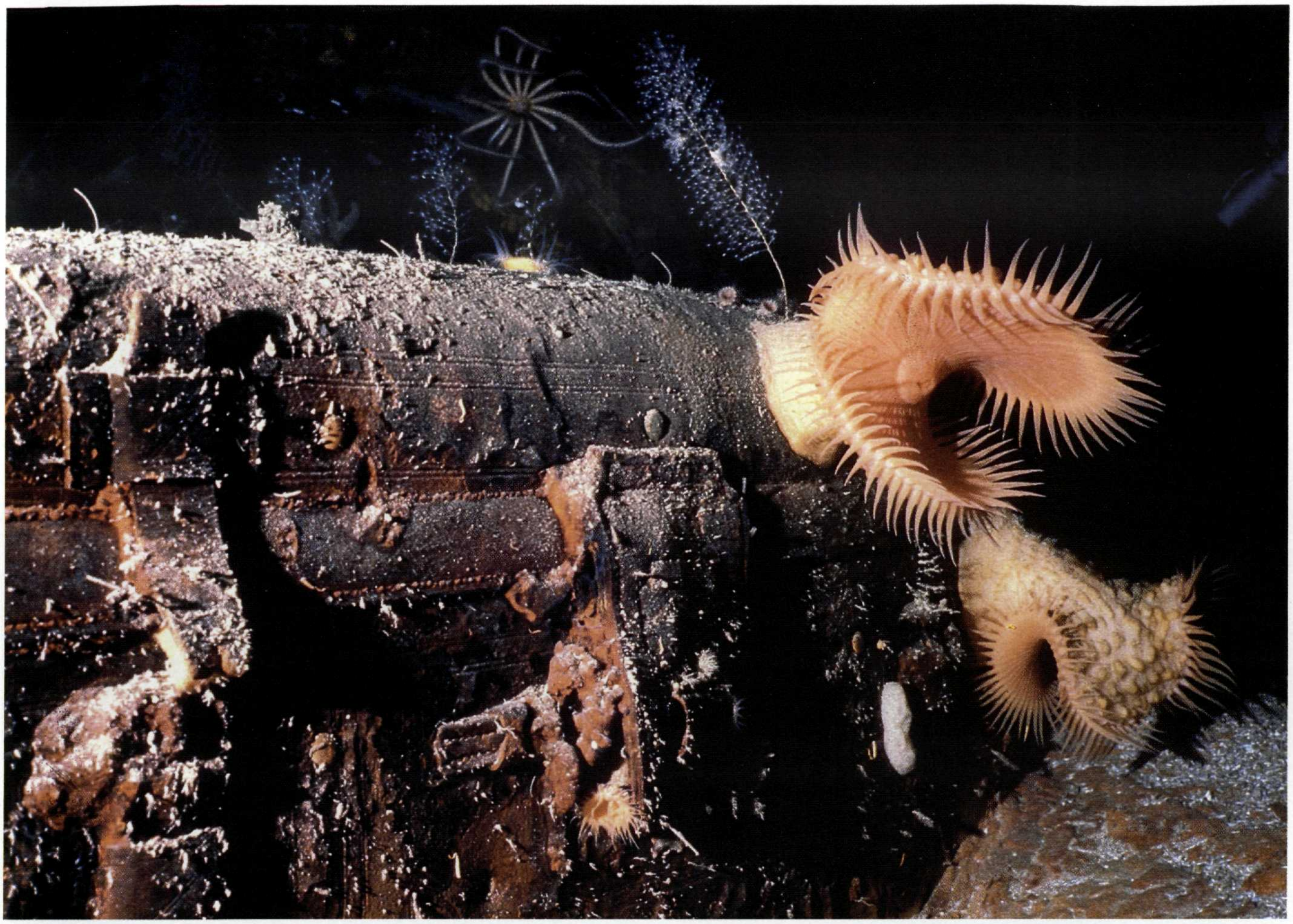


FIGURE 95. A leather trunk is colonized by two large sea anemones (*Paractinostola* new species ?) and a golden coral (*Chrysogorgia* new species). In the background, a large female brisingid sea star (*Brisinga costata*) rests on the remains on the ship's capstan.

over time indicate that anemones on the shipwreck site appeared to live for at least several years.

Order Scleractinia. The stony corals (or madreporarian corals) are closely related to the sea anemones but in contrast, they produce calcium carbonate skeletons and do not possess siphonoglyphs. Some corals are solitary, such as the deep-sea species *Desmophyllum cristagalli* found on the shipwreck (Fig. 96) but the majority are colonial reef-builders with very small polyps. The skeleton is secreted by the epidermis of the lower part of the column and the basal disc. This process results in a skeletal cup (calyx) in which the polyp is fixed. The calyx floor contains thin, radiating, calcareous septa which project upward into the polyp between a pair of mesenteries. Calcium carbonate is continually deposited beneath the living tissue as long as the polyp is alive. Sexual reproduction is similar to that found in sea anemones. A ciliated planula larva settles and attaches to a firm substrate and begins the process of development.

Desmophyllum cristagalli discovered at the shipwreck had a small, white, calcareous skeleton (<2 cm long) which housed the fleshy polyp. A specimen of this species was identified by Dr. Stephen D. Cairns, Department of Invertebrate Zoology, National Museum of Natural History. Videotape of living individuals on the shipwreck showed them to be attached to pieces of structural iron, often in single-file rows of 10 to 20 calyxes. When these corals were feeding, outstretched tentacles appeared to collect fine particles in mucus film or strands which were then directed to the mouth by beating cilia.

FIGURE 96. Stony coral (*Desmophyllum cristagalli*) recovered from the shipwreck of the *Central America*. Photograph courtesy of Dr. Ronald B. Toll.

Order Antipatharia. These cnidarians are commonly known as black, or thorny corals. They have a gorgonian-like appearance, forming upright, plant-like colonies. The polyps are arranged around an axial skeleton composed of a black horny material (antipathin) and bearing thorns. Antipatharians are typically animals of the bathyal and abyssal waters of the ocean (Hyman 1940). Antipatharian polyps are dioecious but colonies may be hermaphroditic. Very little is known about the development and larval stages of these animals, particularly in the deep ocean.

Black coral colonies are typically anchored to a firm substrate by a holdfast which is simply an enlargement at the base of the axial skeleton. A colony of an abyssal black coral was recovered from the shipwreck in September 1990. It was about 12 cm long and consisted of numerous branches resembling a palm frond. The branching was alternate and in a single plane. The lower end of the colony consisted of a flattened basal plate which was attached to an iron tank. Rather than being black, it had a pale golden color. Dr. Dennis Opresko, Oak Ridge National Laboratory, identified the specimen as a new species in the rarely collected genus *Hexapathes*.

Order Zoanthidea. The zoanthids are a small group of cnidarians that resemble sea anemones. Most are colonial but some are solitary. They have no skeleton and only one siphonoglyph. Zoanthids inhabit both littoral and deep-ocean waters. Most species habitually grow on other animals (epizoic), such as sponges, other cnidarians, polychaete tubes, and mollusc shells. They are particularly prone to gastropod shells inhabited by hermit crabs. Videotape of a hermit crab moving over the surface of forminiferal ooze clearly showed an anemone-like animal attached to the shell house of the crab (*Parapagurus*). On inspection, the polyp had somewhat the appearance of the zoanthid *Epizoanthus* illustrated by Hyman (1940) or the actiniarian *Paracalliactis*. The polyp was small, less than a centimeter in height, and was reddish-brown in color.

PHYLUM MOLLUSCA

Members of this phylum are among the most familiar marine invertebrates, including snails, clams, squids, and octopuses. Relative to diversity, only the arthropods have more species. The phylum name means "soft," referring to the soft body but a hard outer shell is a character shared by most of its members. Molluscs are distinguished by three primary features: 1) a muscular foot, 2) a calcareous shell secreted by the underlying epidermis, the mantle, and 3) a rasping, feeding organ, the radula. Of the seven classes of living molluscs, three were observed on the shipwreck site: Gastropoda, Bivalvia, and Cephalopoda (Appendix A).

Class Gastropoda

The class name means "stomach foot" and refers to the broad muscular foot which occupies the underside of these animals. Over 80% of all molluscs are gastropods; they include such forms as snails, limpets, nudibranchs, and sea butterflies (Pearse et al. 1987). Unlike bivalves, gastropods have a distinct head with sensory organs. The typical gastropod shell is a conical spire composed of tubular whorls which contain the soft body mass of the animal. Starting at the apex (smallest and oldest whorl), successively larger whorls are coiled around a central axis (columella). The last and largest whorl (body whorl) terminates at an aperture from which the head and foot protrude. The foot of most marine species bears a horny operculum which fits tightly in the shell aperture and acts as a protective lid. Gastropod shells consist of four layers: an outer periostracum composed of horny protein material (conchin) and three inner layers composed of calcium carbonate (outermost one of vertical crystals and the inner two of calcareous sheets over a thin organic matrix). Organic material accounts for about 30% of the weight of the shell. Active secretion of the shell occurs around the edge of the mantle and thus, the shell is increased in diameter and thickness at the same time. Gastropod shells exhibit a seemingly infinite variety of colors, patterns, shapes, and sculpturing (Abbott 1974).

Gastropods are divided into three subclasses. The first, Prosobranchia, include all those marine forms that respire by gills and in which body torsion is evident. The other two are believed to have evolved from this subclass. The second, Opisthobranchia, displays detorsion, in that the body has untwisted, and the shell and mantle cavity are either reduced in size or absent. Both of these subclasses were well represented on the shipwreck site. The third, Pulmonata, includes the land snails in which the gills have disappeared and a cavity in the mantle has been modified into lungs (Boss 1982).

Five families of prosobranchs were identified from shell material recovered from the SS *Central America* site, representing 13 species (Appendix A). A deep-sea trochid, *Solariella infundibulum,* had a beaded, pyramidal shell and is thought to be herbivorous, grazing on organic debris that settled on the ocean floor. Nine species within the family Turridae had spindle-shaped shells and are believed to be carnivorous. The other three families include two pelagic heteropods, *Atlanta peroni* (Fig. 97) and *Carinaria lamarcki,* and the small floating janthinid, *Janthina exigua.* A number of gastropods have adaptations for a pelagic existence, including the heteropods in which the foot has become modified as an effective fin-like swimming organ. *Atlanta* and *Carinaria* are compressed laterally and the foot is transformed into a vertical fin. Shells are greatly reduced in heteropods but they were occasionally found in the sediment ooze at the shipwreck site. A few prosobranchs are planktonic and stay afloat by means of bubbles. Violet shells, *Janthina,* float beneath a raft of mucus bubbles, secreted by the foot, to which egg capsules are attached to the underside. Some *Janthina* shells found their way to the ocean floor at the *Central America* site where they became incorporated in the sediment ooze and were occasionally noted by their conspicuous purple color.

Six opisthobranch families (23 species) were also found on the shipwreck site (Figs. 97, 98). Two of the families have bubble-shaped shells and are represented by *Cylichna* and *Bulla* in sediment samples. These were

FIGURE 97. Pteropod and heteropod shells isolated from a sediment sample collected at the shipwreck site. The spiral heteropod (top) is *Atlanta peroni*. Pteropod species are illustrated and identified in Fig. 98. The diameter of the sample container is 10 cm.

typically infaunal carnivorous gastropods that burrowed in the sediment ooze for their prey. The remaining opisthobranchs belong to the order Thecosomata, the shelled pteropods (Appendix A). Pteropods (sea butterflies) are planktonic snails that inhabited the near-surface waters in great abundance over the shipwreck site. Their shells ranged in size and shape from a needle to a fingernail. Like the globigerinoid foraminiferans, pteropods also feed on plankton in the upper layers of seawater but unlike the single-celled animals, they are capable of active swimming using modified portions of their mantles (parapods). By rapidly beating these winglike parapods, they can move swiftly through the water to capture their prey. Most shelled pteropods lack gills, thus, gas exchange occurs across the general body surface. Approximately 20 species of pteropods were found in the shells which made up the sediment ooze surrounding and within the shipwreck.

After the tests of foraminiferans, the next most abundant type of shells found in the sediment in the vicinity of the *Central America* were the remains of pteropods. Pteropods normally compose <20% of the shell material in Blake Ridge sediments but near the hull of the *Central America* this percentage increased to about 60% (Table 9). Sediment with such a high concentration is known as pteropod ooze. Presumably the ratio of foraminiferans to pteropods raining down on the ocean floor was a relatively uniform 5:1 for a number of kilometers surrounding the shipwreck. The wreck, which at places rose 5 to 7 m above the bottom, apparently modified the bottom currents yielding a hydrodynamic acceleration which either winnowed out the forams, leaving the larger pteropod shells as a lag deposit or created an energy shadow within the hull where suspended pteropod shells settled to the bottom.

Pelseneer (1888) was the first to record pteropod shells in the sediments collected by the *Challenger* Expedition and to use the term "pteropod ooze." This term is now applied to any pelagic sediment containing at least 30% calcium carbonate of organic origin, of which pteropod and other pelagic mollusc shells are the important constituent (Sverdrup et al. 1942). Pteropod ooze is found primarily in tropical and subtropical zones, and for physico-chemical solution reasons (see Physical Science section earlier in this paper) is usually restricted to depths not exceeding 2,800 m in the Atlantic Ocean. Several studies indicate that the assemblage of pteropod shells in recent sediments generally reflects the environmental conditions and populations of species living in the water column (Lalli and Gilmer 1989).

Gastropods exhibit many types of feeding strategies—herbivores, carnivores, scavengers, deposit feeders, and suspension feeders are all represented in this class. In most gastropods, the radula is employed in feeding and it has become a highly developed organ, acting as a grater, rasp, brush, cutter, grasper, or conveyor. Many marine prosobranchs are herbivorous, feeding on fine algae that can be rasped from rocks or plant surfaces. The tiny snail *Litiopa* is common on floating mats of *Sargassum* in the Sargasso Sea (Barnes 1987). A number of marine families of prosobranchs are carnivorous with their radulas variously modified for cutting, grasping, tearing, and scraping. Many burrow into the sand to find prey while others are adapted for drilling holes in the shells of prey. In the deep sea, deposit feeders and grazers feed on accumulations of organic debris. Suspension feeding is common in others by using elongated gill filaments to trap plankton on mucus sheets.

Most prosobranchs are dioecious. In primitive prosobranchs there is no copulation and fertilization takes place in the seawater after the eggs and sperm are released from the body. In all other gastropods, there is copulation and internal fertilization. A small number of prosobranchs are hermaphroditic, particularly in the sessile forms. Egg deposition in gelatinous strings, ribbons, or masses is characteristic of most advanced prosobranchs and opisthobranchs. Free-swimming trochophore larvae are found only in the primitive prosobranchs that shed their eggs directly into seawater. In other gastropods, the trochophore stage is suppressed and is passed before hatching. More characteristic of marine gastropods is a free-swimming larval type called a veliger. The veliger larva has a swimming organ, called a velum, which consists of two semicircular lobes bearing long cilia. As development proceeds, the foot, eyes, and tentacles appear. The shell begins its spiral development in the veliger stage. As development continues, the veliger reaches a point at which it can no longer swim by means of the velum and settles whereupon metamorphosis occurs.

Class Bivalvia

Pelecypoda, the alternate name for this class, refers to the hatchet-shaped fleshy foot that can be projected from between the two halves of the shell. Clams and their relatives are flattened laterally and possess a shell with two hinged valves that completely enclose a soft body. The shell consists of two similar, generally oval valves that are attached by an elastic ligament and articulate along the dorsal edge. Some species also have

PTEROPODS FOUND ON THE SS *CENTRAL AMERICA* SITE

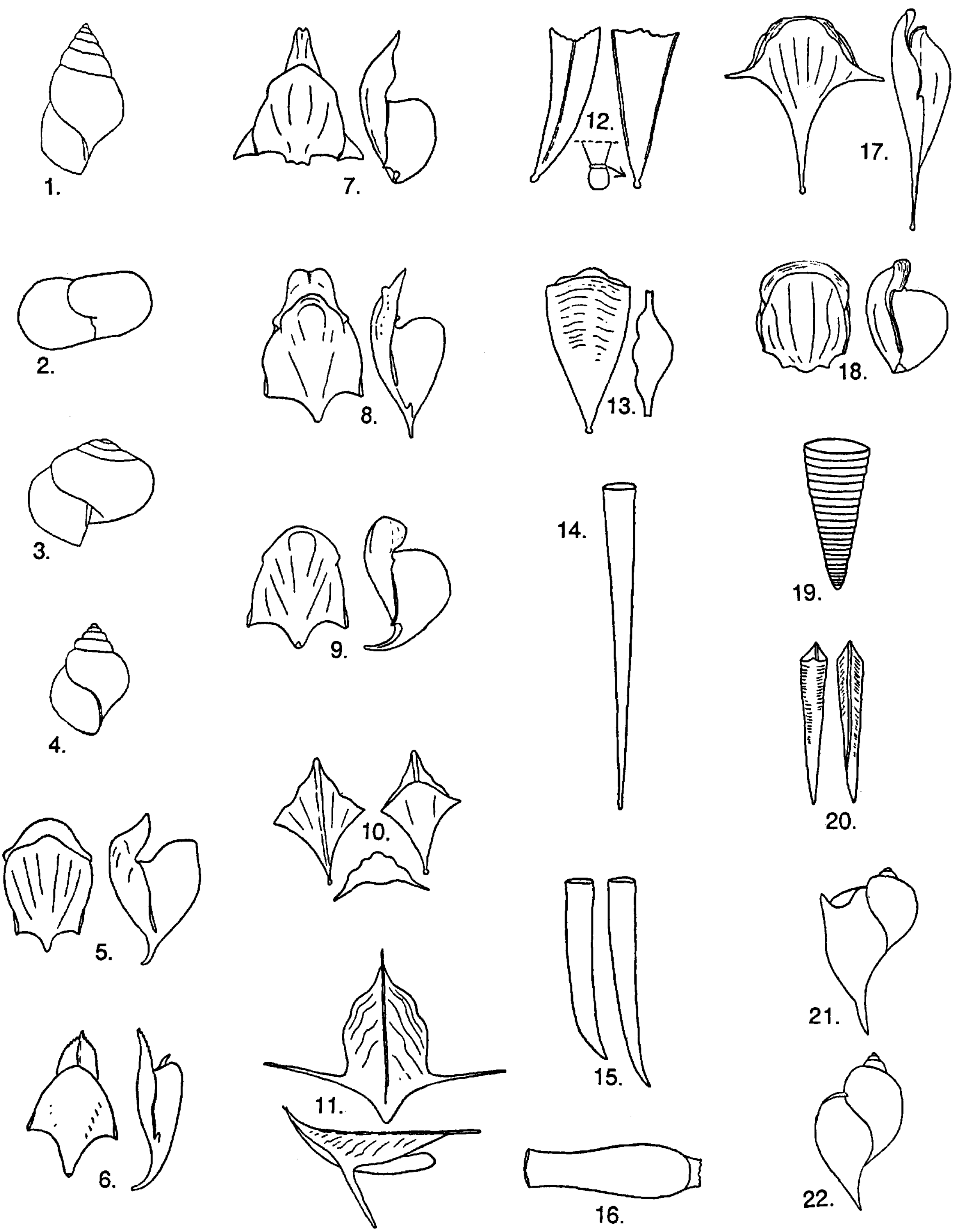


FIGURE 98. Pteropod shells typical of the SS *Central America* shipwreck site. Family Limacinidae: 1. bulimoid pteropod (*Limacina bulimoides*), 2. planorbid pteropod (*Limacina inflata*), 3. Lesueur's pteropod (*Limacina lesueuri*), 4. trochiform pteropod (*Limacina trochiformis*); Family Cavoliniidae: 5. humpback cavoline (*Cavolinia gibbosa*), 6. inflexed cavoline (*Cavolinia inflexa*), 7. long-snout cavoline (*Cavolinia longirostris*), 8. three-toothed cavoline (*Cavolinia tridentata*), 9. uncinate cavoline (*Cavolinia uncinata*), 10. pyramid clio (*Clio pyramidata*), 11. cuspidate clio (*Clio cuspidata*), 12. two-keeled clio (*Clio polita*), 13. wavy clio (*Clio recurva*), 14. straight needle-pteropod (*Creseis acicula*), 15. curved needle-pteropod (*Creseis virgula*), 16. cigar pteropod (*Cuvierina columnella*), 17. three-spined cavoline (*Diacria trispinosa*), 18. four-toothed cavoline (*Diacria quadridentata*), 19. striate clio (*Hyalocylis striata*), 20. keeled clio (*Styliola subula*); Family Peraclididae: 21. two-spined pteropod (*Peraclis bispinosa*) and 22. reticulate pteropod (*Peraclis reticulata*). After Abbott (1974). Drawings not to same scale.

interlocking hinged teeth. The oldest part of the shell (umbo) is an elevated knob near the anterior end, while the posterior end has openings or sipon tubes through which water currents enter and exit. The valves are pulled together by two adductor muscles which work antagonistically. Prominent scars can be found on the inner surfaces of the valves where these muscles are attached. Like gastropods, bivalve shells are composed of an outer periostracum covering several calcareous layers. The shell is enlarged, as the animal grows, by secretions from the mantle. Successive layers of shell, each projecting beyond the last, result in a series of concentric growth lines. Within the shell, the visceral mass lies between the adductor muscles and is covered by a two-lobed mantle. The mantle cavity and the fleshy foot lie between the mantle lobes. A water current flows into the mantle cavity through an incurrent opening and out through an excurrent opening. Suspended in the cavity, on either side of the foot, are a pair of large gills covered with cilia which create the current. The gills are used for food collecting and gas exchange. Most bivalves are laterally compressed, a modification that enhances their ability to borrow in soft sediment. Several bivalve families found at the shipwreck site adopted this strategy while others were specialized for boring into the ship's timbers.

Typically, bivalves lie partly buried in the sand or mud with their hinge up and valves slightly agape. Movement is a slow process. The foot is extended into the sediment and becomes swollen to form an anchor. Water from the mantle cavity is expelled to loosen the sediment and ease the initial movement of the foot. The foot muscle is then contracted, drawing the shell forward. Infaunal bivalves inhabiting soft bottoms exploit the protection offered by being buried in the sediment while utilizing food suspended in water above the bottom. The small Venus clam, *Dosinia*, found in the sediment ooze at the shipwreck, was an example of this type of bivalve. Members of the family Mytilidae are epifaunal and have colonized firm substrates by attaching their shells to the hard surfaces. Attachment is provided by byssal threads, consisting of a tough proteinaceous material secreted by the foot, that fuse the valve to the hard surface. On the shipwreck site, wood, coal, and iron provided a habitat for the mytilid *Amygdalum*. Members of the families Cuspidariidae and Poromyidae are carnivores which inhabited the shipwreck site; *Cuspidaria obesa* senses and locates microcrustacean prey by means of specialized cilia on the incurrent sipon and then rapidly sucks them into the mantle cavity (Reid and Reid 1974) while *Poromya neaeroides* also catches microcrustaceans but uses a hood-like structure which scoops prey into the mantle cavity (Allen and Morgan 1981).

Bivalves of the families Pholadidae and Teredinidae are capable of boring through wood, shell, and even rock. Drilling is achieved by the anterior end of the shell which is sculptured into cutting teeth. Drilling movements include upward and downward cutting, rocking motions, and rotary actions. When drilling, the valves are gaped widely and the foot is extended and made turgid to grip the sides of the burrow. Videotape and samples of the ship's timbers show that the SS *Central America* had been heavily impacted by marine borers. The authors, in collaboration with Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University and Dr. Ronald B. Toll, Department of Biology, Wesleyan College, have initiated a series of studies focused on the wood-boring molluscs that infested the shipwreck. Preliminary results of these investigations indicated that several species of pholadids (most likely *Xylophaga abyssorum* and *Xyloredo nooi* and possibly two undescribed species of *Xyloredo*) had riddled the ship's wooden parts. There was also some evidence of teredinid borings which indicated that the ship had been infested to some degree by shipworms before the sinking, most probably by *Psiloteredo healdi* and *P. megotara*. The degradation of the ship's timbers by marine borers is discussed in detail in the Materials Science section later in this paper.

During a circumnavigation of the world oceans by the R/V *Galathea* in the 1950s, 12% of all deep-bottom stations (400 to 7,300 m depth) yielded woody material of sufficient size to support wood borers. Only half of these samples contained borers (Knudsen 1961). Turner (1973) concluded that the ranges of deep-sea borers (subfamily Xylophagainae) are limited because of poor dispersal efficiency of their larvae and because wood in the deep ocean is scarce (typically found only in "islands" of plant debris off the mouth of large rivers). Based on the present study, wooden shipwrecks can be added to this list. Within the subfamily Xylophagainae, *Xyloredo* differs from *Xylophaga* by having: 1) a long, teredinid-like burrow with a calcareous lining, 2) a thin periostracal sheath extending within the tube from the valve to the terminus, and 3) extended incurrent and excurrent canals. The siphons of *Xyloredo* are short and separate, and resemble a shipworm (i.e., *Teredo*) without its pallets. A mesoplax is present. Species of *Xyloredo* also superficially resemble the teredinid shipworms in that they produce long, often tortuous tunnels which have a calcareous lining and their valves are similar in appearance. Unlike the Teredinidae, *Xyloredo* has short broad ctenidia (comblike gills), and all of the visceral mass is contained between the valves. The lack of pallets for closing the burrow and the lack of an apophysis for attachment of the foot muscle, which are both present in teredinids, place *Xyloredo* in the family Pholadidae, subfamily Xylophagainae.

Several large stromboid bivalves, most likely the pink conch (*Strombus gigas* Linnaeus, 1758), were photographed in the debris field near one of the passenger trunks (Fig. 99). These shells were approximately 20 cm long and exhibited the characteristically pink flaring outer lips of *S. gigas*. *Strombus* is a shallow-water genus of the West Indies and not expected at these depths. Perhaps the shells were souvenirs collected by a passenger during the short layover of the SS *Central America* in Havana on 7 and 8 September 1857. Another possibility is that the shells were collected along the Pacific coast of Mexico or Panama. However, the only Pacific conch large enough to fit the observations is the giant eastern Pacific conch (*Strombus galeotus* Swaimson, 1823) but this species was too smooth-shouldered to match those photographed at the site.

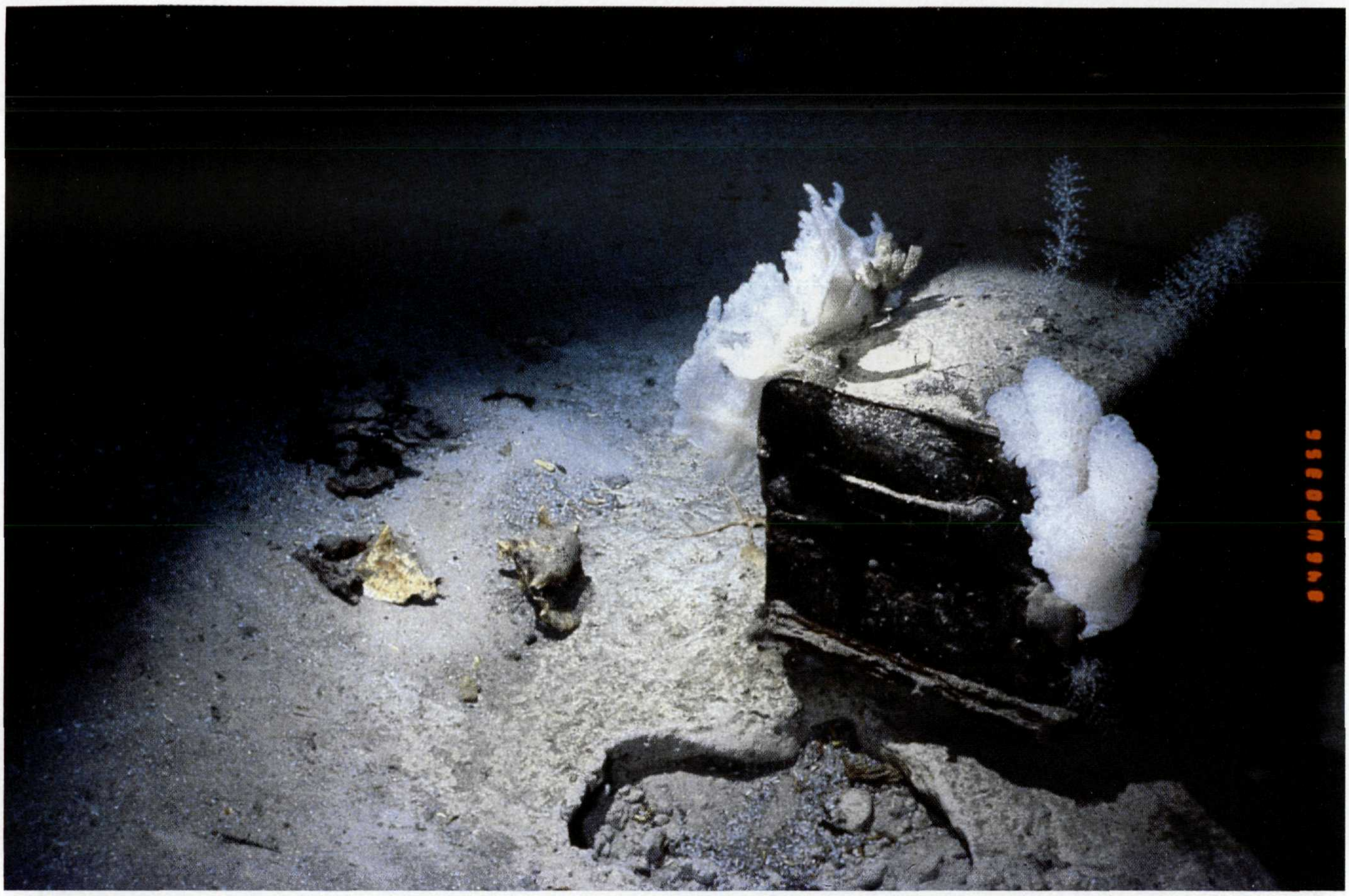


FIGURE 99. Two large stromboid bivalves, most likely the pink conch (*Strombus gigas*), lie in the debris field near a leather trunk. Because *Strombus* is a shallow-water genus of the West Indies and not expected at these depths, the shells may have been souvenirs collected by a passenger during the port call in Havana. The two large white forms on the trunk are hexactinellid sponges. The one on the right is *Calyptorete* and on the left is probably *Chonelasma*. The grayish branching sponge, also on the left, is *Rhabdodictym*. Between the sponge, two feathery gorgonian corals (*Chrysogorgia* new species) are also anchored to the top of the trunk and another one can be seen at the lower right corner of the trunk. An orange brittle star, *Ophiomusium lymani*, crawls over the sediment ooze at the left side of the trunk. The ooze is much finer-grained here in the debris field, some 50 m astern of the shipwreck, than within the hull area. This can be seen in the shallow depression in front of the trunk. The fine ooze is composed of foraminiferal tests. A thin veneer of coarser pteropod shells can be seen at the far left side of the photograph.

The majority of bivalves are dioecious, including members of the subfamily Xylophagainae but there is no copulation. A few marine borers are also hermaphroditic. Fertilization typically occurs in the surrounding seawater as eggs and sperm are shed out with the excurrent water but internally fertilization does occur in some species of *Xylophaga* (Culliney and Turner 1976). The first larval stage is a trochophore; next is a veliger stage, as in gastropods. The veliger eventually becomes enclosed within the two valves and settling occurs. Settling may involve considerable testing of the substrate and delayed metamorphosis, particularly in certain marine borers which will only settle on wood.

Class Cephalopoda

Cephalopods form a highly evolved class of the phylum Mollusca. Deep-ocean representatives of this class include squids and octopuses. With the exception of the nautiloids, cephalopods have no exterior shell and move by means of a muscular foot that is divided into several appendages or arms and tentacles. They have excellent eyes, a mouth with a rasping organ (radula), and a horny beak. Squids and octopuses are voracious feeders who generally prey on crustaceans and fish using their sucker-covered arms to catch and hold the prey and their beaky jaws to tear the prey apart. Squids move quickly by drawing water into the mantle cavity and then forcibly ejecting it; this movement is a backward jet propulsion.

Order Teuthoidea. Flying squids (*Ommastrephes bartramii*) were often attracted to the night lights of the R/V *Arctic Discoverer* and several 30-cm long individuals were captured with baited hooks at the ocean's surface. When one was placed in a confined space (50-l clear-plastic container) and agitated, its swimming became very rapid, its coloration changed from a purplish silver to red, its speckling became more intense, and finally the squid expelled a brownish-black fluid. The ejection of this "ink" is thought to be a form of camouflage which permits the squid to escape from predators, as well as a toxin to predators and prey. In the confined space, the squid was apparently not able to survive the effects of its own ink.

Order Octopoda. Octopods inhabiting the continental slope are muscular but soft and somewhat gelatinous. They are generally pinkish to light red. Most of them have rather short arms as compared to the littoral species (Voss 1967, Marshall 1979). They can alter their color to match their surroundings and, like the squids, they can produce ink and move rapidly backward by water-jet propulsion. Octopods are solitary animals that live among rocks or in holes. A single individual was photographed in 1987 scurrying over the sediment on the Blake Ridge near Site H. Presumably, the ironworks and debris from the shipwrecks provided ample places of seclusion for such creatures. Video images of a large individual (50-cm mantle, 2-m arm spread) on the SS *Central America* site were obtained in September 1991 (Fig. 100) when the animal explored the submersible *Nemo* by climbing all over the craft and out on its camera and lighting booms. Dr. Ronald B. Toll, Wesleyan College and Dr. Janet Voight, Field Museum of Natural History, preliminarily identified this visitor as a female *Pteroctopus tetracirrhus* or *Benthoctopus oregonae.* Additional images were reviewed by Dr. Clyde F. E. Roper, National Museum of Natural History and Dr. Michael Vecchione, National Marine Fisheries Service, and they concluded that the octopus was a new species in the genus *Benthoctopus.*

Octopods are thought to have evolved from free swimming cephalopods but they have reverted to a more benthic existence. The body is globular, fins are lacking, and there are no traces of the shell. As the name suggests, octopods have eight arms (tentacles) each equipped with adhesive suction discs. These suckers carry a large number of chemical and tactile receptors (Morton 1979). The arms are arranged in a circlet linked by a web around the mouth. Octopods are capable of swimming by jetting water out of a muscular funnel (siphon). This organ has developed from the foot and is located behind the head, close to where the head is fused to the mantle. A strong jet of water propels the animal in a backward direction with the arms trailing. However, octopods more frequently crawl in a forward direction over the ocean floor where they live. The suction discs are used to pull the animal along or anchor it to the substrate. Most octopods occupy a den or retreat from which they make feeding excursions, often ambushing their prey. At the shipwreck site, an octopus was videotaped entering its apparent lair, a cavernous opening in a jumble of ship timbers.

Octopods hunt by leaping on motile prey and enveloping their victim within the octopods' outstretched arm web. This particular behavior was observed in August 1991 on the wreck of the *Central America* when an octopus captured and consumed a galatheid crab. Octopods possess a pair of powerful and dexterous, beak-like jaws which can bite and tear off large pieces of tissue. The food item is then pulled into the mouth cavity by the tongue-like action of the radula which

FIGURE 100. A deep-sea octopus (*Benthoctopus* new species) glides over the sediment ooze within the shipwreck of the *Central America.* The ooze is composed of the tests of single-celled foraminiferans and the shells of pelagic snails (pteropods). A brittle star (*Bathypectinura heros*) can be seen under the leading arm of the octopus.

bears many rows of small, chitinous teeth. Behind the radula are a pair of salivary glands which secrete digestive fluids as well as a poison which can enter the tissues of the prey through the wound inflicted by the jaws (Barnes 1987). Absorption of food takes place in the digestive gland located in the mantle. Wastes leave the anus near the funnel and are carried away with the exhalant water jet.

The eyes of octopods are highly developed and show convergent evolution which has yielded eye structures similar to those of fishes. Experiments have shown that *Octopus* can discriminate objects as small as 0.5 cm from a distance of 1 m (Wells 1978). The lens is capable of forming distinct images and the optical connections appear well adapted for analyzing vertical and horizontal projections of objects which are of considerable advantage in capturing prey. Even though the shipwreck lies within a region of perpetual darkness, the octopod's behavior, in particular its responses to *Nemo*'s lights, indicated that it had functioning eyes.

PHYLUM ANNELIDA

Class Polychaeta

Polychaetes include familiar marine forms such as bristle worms and feather-duster worms. They are often strikingly colorful and show considerable variation in form and life style. Polychaetes can be errant (free moving) or sedentary. The errant ones include some species that are strictly pelagic, some that crawl over the ocean floor, and some that are active burrowers in sand and mud. Most sedentary species construct and live in permanent burrows or tubes. Polychaetes are distinguished from other wormlike animals by their segmentation (metamerism). The rings on their elongated, soft bodies are an expression of internal, as well as, external segments which are arranged in a linear series along an anterior-posterior axis. The segmented part of the body is limited to the trunk and does not include the head (prostomium) or terminal part (pygidium) that carries the anus. The formation of new segments takes place just in front of the pygidium, thus, the oldest body segments are just behind the head. Metamerism appears to have evolved in annelids as an adaptation for burrowing in soft substrata (Barnes 1987).

Polychaetes are usually less than 10 cm long and 2 to 10 mm in diameter. The polychaete skin (integument) is composed of a single layer of epithelium covered by a thick collagen cuticle. Mucus-secreting glands are located in the epithelium. Most large polychaetes possess gills or modifications of the parapodia to facilitate gas exchange. The head is well developed and bears several sensory organs: brain, eyes, and antennae. The eyes of most polychaetes can only detect light intensity. The mouth is located on the ventral surface toward the base of the head. Polychaetes have no solid skeleton but gain rigidity from hydraulic pressure in the fluid-filled body cavity (coelom). Alternate contraction of two sets of muscles allows them to move. Contraction of the longitudinal muscle causes the coelomic fluid to exert a force which widens the body, while contraction of the circular muscles causes the body to elongate. Because of the compartmentalization, waves of peristaltic contraction pass along the body, bringing about elongation and then shortening sequentially in each segment. Thus, as each segment swells it is anchored to the burrow wall and then when the segment elongates, the animal is thrust in a forward direction. Bristles on each segment increase traction as the animal moves through its excavation. Each body segment bears a pair of fleshy, paddle-like appendages called parapodia. The parapods have small pockets from which numerous chitinous bristles project. This feature gives the class its name.

Polychaetes with an errant life style include pelagic swimmers, bottom crawlers, and active burrowers, all of which had representatives at the shipwreck site. Several families of polychaetes contain exclusively planktonic or pelagic species. Microscopic examination of *Sargassum* mats, collected on the ocean surface above the site, revealed numerous, nearly transparent, planktonic forms of these worms (most likely tomopterids). Large eyes and reduced bristle size were common in these worms. Swimming is accomplished in this group by body undulations which are produced by paddle-action of the parapodia. The bottom crawlers dwelled on the ocean floor, often living beneath timbers, coal, and other hard material at shipwreck site. Many possessed the generalized body form of a typical polychaete worm, such as the scale worm, *Eulagisca*, recovered from the site in a pteropod ooze sample. This worm was identified by Dr. Kristian Fauchald, National Museum of Natural History, Smithsonian Institution, by examination of the peculiar plate-like scales on the dorsal side of the body. The scales are thought to provide a channel for ventilating currents when the worm is wedged beneath rocks or burrowing in sand or mud.

Crawling polychaetes were captured on videotape at the shipwreck site on a few occasions. The most notable was when a relatively large (7 cm) nereid worm, *Nereis*, was captured by a brachyuran crab and the crab was attacked by an ophidiid fish. The crawling motion of these worms is brought about by the combined action of the parapodia and musculature and to some extent the coelomic fluid. The parapodia and bristles push against the substratum in a wave-like motion. For a slow crawl, only the parapodia are used but for fast movement the longitudinal muscles throw the body into an undulating wave. Nereids, like the ones observed on the shipwreck, are also capable of a swimming motion similar to that described for pelagic worms. Other polychaetes are adapted for burrowing and construct a system of mucus-lined galleries. Typically, they have small, pointed heads, the eyes and antennae are absent and parapodia tend to be smaller than surface crawlers. They also move through the ocean sediments by peristaltic contraction. Some burrowers become sedentary once the burrow has been constructed. The soft sediment ooze surrounding the shipwreck contained numerous burrows (Fig. 78) which may be attributed to these polychaetes.

Polychaetes with a sedentary life style include tubicolous worms and borers. However, not all tubicolous polychaetes are sedentary. Errant quillworms, order Eunicida, were common in the sediment ooze at the their shipwreck site. The species *Hyalinoecia artifex* constructed secreted, translucent, quill-like tubes, which laid horizontally on the ocean floor. Video transmissions showed that these animals were capable of moving their elongated tubes freely over the bottom. Other members of this group live in fixed tubes of secreted materials or cemented sediment grains and rarely leave them. The tube may serve as a protective retreat or a place of concealment from passing prey (Barnes 1965). At the shipwreck site, polychaetes in the orders Chaetopterida and Sabellida used this strategy by attaching their tubes to metalworks, timber, coal, and pottery artifacts. Chaetopterid worms, such as *Spiochaetopterus*, built amber-colored membranous tubes which were abundant among hard objects recovered from the shipwreck. Specimens of this worm were also identified by Dr. Fauchald, National Museum of Natural History. Among the most showy of the sedentary polychaetes are the feather-duster worms of the family Serpulidae. Palps have developed in the head region to form funnel-shaped or spiral crowns consisting of pinnate processes called radioles. The radioles are rolled up or closed when the worm withdraws into the tube. The most dorsal radiole of a serpulid is modified into a stalked operculum, which acts as a protective plug at the end of the tube when the crown is withdrawn. Those found on the shipwreck, such as *Ditrupa*, secreted calcareous tubes (1 to 8 cm) which were common on hard materials recovered from the site (Fig. 167 in the Underwater Archaeology section). Their white tubes were more or less cylindrical and often irregularly coiled and somewhat tapered or tusk-shaped (Fig. 101). Dr. Mary E. Rice, National Museum of Natural History, Smithsonian Marine Station at Link Port, examined samples of wood recovered from the SS *Central America* and confirmed the presence of worm tubes from the family Serpulidae. A number of other polychaetes excavate protective retreats within shells and other bottom materials. Boring is begun by a newly settled young worm and the adult animal usually remains in the excavation throughout its life.

FIGURE 101. Gold coins scattered on the wreckage of the SS *Central America*. A large brown calcareous tube, constructed by a wood-boring bivalve, can be seen at upper right and bright white tubes made by a serpulid worms at center and lower left.

Feeding methods of polychaetes are closely related to their various life styles. Thus, polychaetes can be grouped into the following types: 1) raptorial feeders, 2) herbivores, omnivores, scavengers and browsers, 3) nonselective deposit feeders, 4) selective deposit feeders, and 5) filter feeders. Most pelagic and surface dwelling, errant polychaetes are predacious but some are herbivorous or scavengers. The prey consists of various small invertebrates and other polychaetes. Most sedentary burrowers are deposit feeders. Tubicolous polychaetes are typically deposit feeders or filter feeders. Serpulid worms form a funnel when expanded outside the end of the tube. Beating of the cilia located on pinnules in the radioles produces a current of water that flows up through the radioles. Particles are trapped on the pinnules and are driven by cilia into a groove running the length of each radiole to the mouth. Sorting of food particles takes place in a chamber at the base of each radiole.

Polychaetes have few protective body structures except for the bristling setae on each segment that have a powerful sting. Many polychaetes build tubes, seclude themselves under rocks, or burrow into sediment in such a way as to shelter themselves from predators. When exposed, polychaetes fall prey to a great number of animal groups, including sea anemones, hydroids, corals, various worm groups, crustaceans, sea stars, brittle stars, and fishes.

Most polychaetes are dioecious but copulation is rare. Commonly, fertilization takes place in seawater after synchronous emission of eggs and sperm. A planktonic trochophore larva is the typical type for most polychaetes. During metamorphosis, the larva elongates and becomes constricted into segments. In benthic forms, the young worm then settles to the bottom, begins to form a tube, and continues to grow throughout its life. Epitoky, the formation of a pelagic reproductive individual (epitoke), is a polychaete dispersion mechanism for leaving bottom burrows or tubes and thus increases the likelihood of fertilization (Pettibone 1982).

PHYLUM ARTHROPODA: Subphylum Crustacea

This phylum includes a vast assemblage of animals, including insects, spiders, and crustaceans. Only the subphylum Crustacea and a few sea spiders (subphylum Merostomata, Class Pycnogonida) have representations in the deep ocean, and only the crustaceans have been observed on the shipwreck. Two crustacean classes, Malacostraca (isopods, amphipods, and decapods) and Cirripedia (barnacles), contributed conspicuous members to the benthic community at the site.

The annelidan ancestry of crustaceans is reflected in their segmentation (metamerism). Arthropods move by jointed segmental appendages, rather than by deforming the body like most other animals. They have a chitin-protein exoskeleton (carapace) that is divided into plates and cylinders that make movement possible, as well as, periodic molting of the exoskeleton which permits growth. The skeleton and muscles (attached to the inside of the skeleton) operate together as a lever system. The circulatory system in arthropods is open and they possess a primitive, tubular heart. There is a high degree of cephalization with a sizable brain and well-developed sense organs, such as compound eyes and two pairs of antennae. Other head appendages include one pair of mandibles (mouthparts used for biting and crushing food) and two pairs of maxillae (mouthparts used as accessory jaws). Crustacean appendages are typically biramous (branched) and are adapted for many different functions including walking, swimming, feeding, reproduction, and gas exchange. Most crustaceans are dioecious, and copulation and internal fertilization are characteristic of the majority of species, with various appendages involved in courtship and sperm transfer. Egg brooding is common and a free-swimming, planktonic larva (nauplius) is characteristic of most marine species. The advanced larva (zoea), after successive molts, acquires trunk segments and additional appendages until a full complement is achieved.

Class Malacostraca

The trunk of a malacostracan is typically composed of 14 segments, plus the tail (telson). The first eight segments form the thorax and the last six form the abdomen, all of which bear appendages. The thoracic appendages (pereopods) are leg-like and modified for crawling or grasping. Generally, the anterior five pairs of abdominal appendages (pleopods) are variously modified for swimming, burrowing, ventilating, carrying eggs, and gas exchange. In males, the first pair of pleopods are usually modified for copulation. The sixth abdominal appendages (uropods) consist of a large flattened surface, and together with the telson, form a tail fan, which is most frequently used in escape swimming.

Order Isopoda. Isopods normally have seven pairs of legs that are about equal in size, a feature from which the order name is derived. The head is typically shield-shaped and often united with the thorax. The coloration in isopods is usually drab, shades of grayish brown to white being the most common. Isopods are primarily benthic animals and most are adapted for crawling over soft bottoms. Many isopods burrow and some construct tunnels through marine sediments, packing excavated material against the walls. Other species can swim using their pleopods. Most isopods are scavengers and omnivores but deposit feeding is a common mode for many marine isopods. During feeding, the maxillipeds, which form a protective operculum over the mouth parts, open and food is held and moved toward the mouth by the anterior legs, which may be subchelate (pincer-like, but lacking a moveable finger) (Barnes 1987).

Suborder Asellota forms an abundant component of deep-sea benthic macrofauna. There are 16 common genera in this group that have been found in previous studies at depths from 2,000 to 2,400 m off the Carolina coast (Table 12) and were the ones likely to inhabit the sediment ooze surrounding the wreck of the SS *Central America*. Benthic isopods are ideal indicators of depth zones on the ocean floor for several reasons as pointed out by Menzies et al. (1973): 1) isopods develop directly

TABLE 12

Common genera of isopods found in sediments off the Carolina coast at depths of 2,000 to 2,400 m.

PHYLUM ARTHROPODA			
Subphylum Crustacea			
	Class Malacostraca		
Order Isopoda			
Suborder Gnathiidea			
	Family Gnathiidae		
		Bathygnathia sp.	
Suborder Flabellifera			
	Family Cirolanidae		
		Haplomesus sp.	
	Family Serolidae		
		Serolis sp.	
Suborder Valvifera			
	Family Arcturidae		
		Astacilla sp.	
Suborder Asellota			
	Family Acanthomunnopsidae		
		Acanthocope sp.	
	Family Dendrotionidae		
		Dendrotion spp.	
	Family Desmosomatidae		
		Desmosoma spp.	
		Eugerda sp.	
	Family Eurycopidae		
		Eurycope sp.	
	Family Haploniscidae		
		Haploniscus sp.	
		Antennuloniscus sp.	
	Family Ilyarachnidae		
		Ilyarachna sp.	
	Family Ischnomesidae		
		Heteromesus sp.	
	Family Janirellidae		
		Ianirella sp.	
	Family Macrostylidae		
		Macrostylis sp.	
	Family Munnopsidae		
		Munnopsis sp.	

Data Sources: Menzies et al. (1973), Richardson (1905), and Smith (1923).

from a brood-pouch with no plankton or migratory larval stage, 2) most species are obligatory sediment dwellers, 3) they are among the most abundant of deep-sea invertebrates, and 4) their remains are not subject to transport from shallow water by turbidity currents as is the case for foraminiferan and mollusc shells. Thus, isopods found in samples from the shipwreck site provided a realistic view of the fauna at that location and time that is not confounded by secondary biotic or abiotic mixing processes.

Suborder Asellota includes free-living isopods as well as parasites of fish and wood borers. Dr. Thomas E. Bowman, National Museum of Natural History, Smithsonian Institution, identified an adult individual within this group as *Aega gracilipes* which was collected with a suction dredge from the shipwreck. Dr. Bowman indicated that young individuals of this species are parasitic on fish. They are bloodsuckers which are temporarily attached to the fish for a "bloodmeal" while the adults are scavengers. The recovered specimen was 12 mm long and had pigmented (black) eyes which did not merge in the center of the head, a character of this species. Another species in this suborder, *Limnoria lignorum* (common gribble), tunnels through wood and can cause extensive damage to ships, docks, and pilings. This animal, along with teredinid bivalves, may have been responsible for some of the pre-sinking damage to the hull of the SS *Central America.* Wood-boring marine isopods feed on the resulting sawdust. The wood tissue is broken down by secretion of the enzyme cellulase. As the larvae of *Limnoria* settle, they are attracted to fungi in the wood. The fungi add needed nitrogen to their largely cellulose diet (Geyer and Becker 1980). The common gribble is a small isopod (3 mm) that occurs in great numbers and makes borings in the wood just above the low-water mark. The hour-glass shape of many pilings at this tide level is caused by the burrows of this tiny isopod. The existence of a deep-water relative of this species in the timbers of the *Central America* is unknown but is the subject of an ongoing investigation by Dr. Ruth D. Turner, Harvard University, to identify the wood borers which have infested the shipwreck.

Order Amphipoda. Amphipods are crustaceans that are flattened sideways (laterally) and their appendages are used for both swimming and walking, a feature from which the order name has derived. Amphipods were relatively common on the shipwreck of the *Central America* and although quite small (<10 mm), they were conspicuous as a result of their translucent white color, bouncy swimming motion, and lazy crawl over the shipwreck remains.

Amphipods display a convergence in structure with isopods but can be distinguished by the lateral compression of their bodies, giving them a shrimp-like appearance. Also, amphipods possess thoracic gills, whereas isopods have abdominal pleopods modified as gills. The first pair of thoracic appendages are modified as maxillipeds, while the next two are used for grasping (gnathopods) followed by four pair of legs (pereopods). The anterior three pairs of abdominal appendages (pleopods) are used in swimming. The posterior three pairs (uropods) are directed backwards and assist in swimming. Most marine amphipods are scavengers or detritus feeders. Sediment or plant and animal remains are picked up with the gnathopods, or organic detritus is raked from the bottom with the antennae. *Chelura terebrans,* a small amphipod common along the Atlantic coast, bores into submerged wood and like the isopod *Limnoria,* is destructive to pilings but it is unknown if similar amphipod borers had been active on the timbers of the wreck.

Most marine amphipods are in the suborder Gammaridea and they are essentially bottom dwellers though most can swim for short distances. Propulsion for swimming is provided by the pleopods (strokes) and by the uropods (flexions). Gammarids usually swim intermittently between crawling and burrowing. Upon leaving the substrate, an initial thrust is gained by a backward flip of the abdomen. As the amphipod swims, it often rolls over on its side. The last two pereopods can be flexed outward producing a somewhat clumsy, skittering sort of motion when the animal is on its side (Pennak 1989). Members of the gammarid family Lysianassidae are flesh-scavenging animals, including *Paralicella,* an errant scavenger which was often observed scurrying over collapsed timbers and piles of gold coins at the shipwreck site. Another gammarid, *Onesimoides,* was recovered with timbers from the site. This genus is typically associated with submerged wood and plant debris, deriving some nutritional value from these materials. Dr. Jerry L. Barnard, National Museum of Natural History, Smithsonian Institution, examined videotape showing these animals on the shipwreck in September 1990 and provided the above tentative identifications.

Amphipods are dioecious and reproduction is similar to that of isopods in that both groups have a brood chamber (marsupium) beneath the thorax. Eggs are deposited, fertilized, and brooded within the marsupium, where development is direct and postlarva young are hatched. Brooding eggs is a decided advantage in the deep sea. Because the young hatch out in near-adult form, more yolk is required, thus larger and fewer eggs are produced than by those that go through larval stages after hatching. The main advantage is that more mature offspring are liberated in the locality where the parent lives, for example the confines of the shipwreck. The fact that the parent lived to reproduce is a good criterion that conditions are suitable for the existence of the newly hatched individuals (MacGinitie and MacGinitie 1968).

Order Decapoda. Decapods are distinguished from other malacostracans in that the first three pairs of thoracic appendages are modified as maxillipeds. The remaining five pairs of thoracic appendages are legs, from which the order derives its name. Generally the first pair of legs is commonly enlarged and chelate (bearing pincers with a moveable finger). The sides of the overhanging carapace enclose the gills within well-defined branchial chambers. Representatives of at least one infraorder of shrimps (Caridea) and two infraorders of crabs (Anomura and Brachyura) were observed on the shipwreck.

Shrimps have a fused cephalothorax and a flexible abdomen that ends in a fantail. Their bodies tend to be laterally compressed and are covered by a delicate, chitinous, semi-transparent carapace. The cephalothorax often bears a keel-shaped, serrated rostrum.

The pereopods are typically slender and used for crawling, while the pleopods are used for intermittent swimming. Shrimps can also move rapidly backwards by flexing their abdomen and tail. Shrimps are the only pelagic decapods but most shrimps are bottom dwellers. In general, species living in the upper 500 m of the sea are transparent or translucent, while those living deeper are red. Many of the deeper group possess luminescent organs or photophores. Typically shrimps produce thousands of eggs from a single mating, and carry them on the pleopods (swimmerets) while they develop.

Three families of bathypelagic or benthic carid shrimps have been reported in the North Atlantic Ocean at depths in excess of 2,000 m: Nematocarcinidae, Oplophoridae, and Bresiliidae (Abele and Felgenhauer 1982). Based on the body size (5 cm) and morphology visible in the videotape, the abundant carid shrimps on the shipwreck site appeared to belong to the genus *Nematocarcinus* as illustrated in Agassiz (1888). They were robust, conspicuous, red shrimps with a distinct angular bend at the abdomen. The body appendages were very long and slender, and the second antennae were several times the total body length. White membranes (photophores) near their eyes can produce a bioluminescent glow which may be useful in attracting prey or a mate in the darkness of the deep sea. Dr. Thomas E. Bowman viewed videotape of these animals in April 1992 and noted that the eyes appeared to glow because of a feature known as the tapetum, a reflecting surface of guanine crystals at the back of the retina which reflects incoming light toward photoreceptors, thereby nearly doubling the light available for vision. Females of this genus can carry more than 20,000 eggs on the pleopods (Abele and Felgenhauer 1982). The young hatch as zoea larvae.

Crabs are exclusively benthic animals that are more highly adapted for crawling than most shrimps. The body tends to be dorsoventrally flattened and the legs are usually heavier than those of shrimps. The first pair of legs normally are powerful chelipeds and the pleopods are not adapted for swimming except in the family Portunidae. Also, the long-bodied form of the shrimp has been greatly shortened by folding of the abdomen ventrally beneath the anterior part of the body. True crabs (infraorder Brachyura) are at the opposite end of the spectrum from shrimps, whereas intermediate are the anomuran crabs (infraorder Anomura). The latter group includes hermit crabs and galatheid crabs in which the abdomen is never as reduced as in brachyurans but it is often tucked under the cephalothorax. Most anomurans still retain the uropods but the fifth pair of legs is small and commonly directed upward or tucked beneath the sides of the carapace (Bliss 1990).

Anomuran crabs of the family Galatheidae are a group of long-tailed, lobster-like animals that are often referred to as "squat lobsters." The rostrum is distinct and strongly pointed, projecting forward of the eyes. The antennae are generally elongated as are the chelipeds which in some are nearly twice as long as the body (Williams 1984). Galatheid crabs were one of the dominant errant groups in the benthic community at the shipwreck sites (Fig. 102). Their colors varied from white to reddish-orange, violet, and greenish-brown. The stark white individuals showed up as brilliant images even on reconnaissance photographs of the sites. In September 1989 collections were made of galatheid crabs with two modified minnow traps, one baited with beefsteak and the other with lobster (Figs. 55, 56). After a placement period of 10 days on the shipwreck site, the beefsteak-baited trap yielded four specimens of *Munidopsis* and one 6-armed starfish (*Ampheraster alaminos*), while the lobster baited trap yielded only one *Munidopsis*.

FIGURE 102. A galatheid crab rests on the decayed timbers at Site H. The heavy carapace and armored appendages are typical of *Munidopis crassa*.

Dr. Austin B. Williams, National Marine Fisheries Service, Systematics Laboratory, National Museum of Natural History, examined these specimens as well as photographs of other decapods from the site and additional specimens taken in 1990 and 1991. He identified five galatheid species from specimens (*Munida microphthalma* and *Munidopsis bermudezi, M. crassa, M. rostrata* and *M. similis*) and two other possible ones from photographs (*Munidopsis livida* and *M. nitida*). The specimens ranged from 5 to 12 cm in length. One large (10 cm) ovigerous female, *Munidopsis crassa,* taken in September 1989 was carrying approximately 50 eggs on her pleopods (Figs. 103, 104), while a much smaller (5 cm) *Munida microphthalma,* collected in August 1990 had over 200 eggs, and *Munidopsis bermudezi* (7 cm), sampled in August 1991, carried 68 eggs. Dr. Williams noted that only the eyes of *Munida microphthalma* showed pigmentation.

Other than the occasional fishes that entered the viewing area of *Nemo*'s cameras, the most active animals were the galatheid crabs. They were quite common in the timber area of the shipwreck, in the coal piles, and on the ironworks. Turner (1973) noted that a mainstay in the diet of deep-sea galatheid crabs is wood-boring bivalves. The abundance of these molluscs on the shipwreck was evidenced by their numerous burrows in the

FIGURE 103. Dorsal view of a female galatheid crab, *Munidopsis crassa*, from the shipwreck site showing the array of spines. Photograph courtesy of Dr. Ronald B. Toll.

ship's timbers and their countless abandoned tubes. The slender, elongated body and appendages of the galatheid crabs appeared well-adapted to penetrate the burrows in search of prey. Additional food items found in the stomachs of galatheid crabs, living at similar depths in the North Atlantic and associated with submerged wood, were reported by Williams and Turner (1986) as: polychaetes, nematodes, sponges, harpacticoid copepods, asellote isopods, benthic and planktonic foraminiferans, molluscs, and wood fragments.

Anomuran decapods of the superfamily Paguroidea (hermit crabs) are closely related to galatheid crabs but they have evolved the habit of housing their abdomen within gastropod shells. The abdomen is not flexed beneath the cephalothorax but is modified to fit within the spiral chambers of snail shells. The twist of the abdomen is best adapted for right-hand (dextral) spirals. The shell is held in several ways: 1) uropods modified to hook the columella of the shell, 2) contraction of longitudinal abdominal muscles to press the abdomen against the inner walls of the shell, 3) last two pairs of legs push against the wall of the shell aperture, and 4) legs and uropods covered with tubercles to grip the shell interior. Hermit crab growth and reproduction are limited by the supply of adequate snail shells. This factor may explain the relatively high numbers of galatheid crabs as compared to hermits on the shipwreck. Some hermit crabs have a complex commensal relationship with sea anemones which are attached to the shell. When the crab moves to a larger shell, it takes the anemones along. A deep-sea hermit crab of the genus *Parapagurus* was recorded on videotape while it was crawling rapidly over the sediment ooze near scattered timbers of the shipwreck. It was small, about 2 cm in length, and pinkish-white in color. The shell bore a small reddish polyp, that was either a sea anemone or a zoanthid.

Brachyuran crabs have the most highly specialized decapod body in that the abdomen is greatly reduced and fits tightly beneath the cephalothorax. Thus, uropods are lacking and pleopods are only retained by females for brooding eggs, while males retain only the anterior two pairs of copulatory pleopods. The carapace is very broad and commonly wider than it is long, which enhances the flattened appearance of the body. The evolution of abdominal reduction and flexion in true crabs appears to be a locomotive adaptation, shifting the center of gravity forward to a point beneath the crawling appendages (Barnes 1987). Crabs can crawl forward slowly but they normally move sideways, especially when crawling rapidly. Sideways movement involves flexing the leading legs so as to pull the body while the trailing legs push by extending. Crabs do not use the chelipeds for crawling.

Brachyuran crabs are found in all types of marine habitats and to great depths. Many deep-sea crabs, including members of the family Geryonidae which were observed on the shipwreck, have long, slender legs used for crawling over soft bottoms but they support a rather robust body. Dr. Raymond B. Manning, National Museum of Natural History, Smithsonian Institution, reviewed videotape of a large geryonid crab (carapace length about 10 cm; legs span over 30 cm) in April 1992 and concluded that it was a new species in the genus *Chaceon*. One of the few examples of aggressive behavior observed on the shipwreck site involved this crab. In August 1991, a large *Chaceon* was recorded on the sediment ooze where it had captured a nereid bristle worm adjacent to one of the pine test panels at the wood-borer experiment station. While the crab systematically fed on the still writhing worm, an ophidiid fish (*Barathrodemus manatinus*) slowly approached. The ophidiid appeared to have nonfunctioning eyes and moved in slowly, most likely attracted by smell. Suddenly the fish lunged toward the worm. As it struck, the crab retracted its eye stalks

FIGURE 104. Ventral view of a female galatheid crab, *Munidopsis crassa*, from the shipwreck site showing eggs held on the pleopods. Photograph courtesy of Dr. Ronald B. Toll.

and pulled the worm under its carapace. Later the fish made another attempt but this time the crab was more aggressive and the fish was driven off.

Decapods have a ventral mouth which is flanked by stacked feeding appendages. The third maxillipeds are the outermost of these and are over the other two appendages. Food is typically caught or picked up with the chelipeds and then passed (much like being placed on a conveyor belt) to the third maxillipeds, which push it between the other mouthparts (mandibles). While a portion is bitten or held by the mandibles, the remainder is torn away by the maxillipeds. The piece held by the mandibles is then directed to the mouth. This process was clearly visible in the videotape of the geryonid crab eating the polychaete worm.

Decapods exhibit a wide range of feeding habits and diets but the majority of species couple predacious feeding with scavenging. Large invertebrates are common prey, including polychaetes, bivalves, echinoderms, and other crustaceans. The shape of the chelipeds often reflects feeding habits. Species that scrape rock or feed on detritus at the sediment surface usually have chelipeds with spoon-shaped fingers. Species that feed on shelled molluscs have dimorphic chelipeds: the heavier right claw bears blunt teeth in the fingers for crushing and the more slender left claw is adapted for cutting. Most shrimps are omnivores, some are scavengers. Opportunistic feeding habits such as these make these animals well-suited for deep-sea living where food supplies are often scarce. Hermit crabs are primarily deposit-feeders and scavengers. Their most frequent method of feeding consists of scooping up sediment and sorting it with the mouth parts. This mode of feeding by hermit crabs and some galatheids explains their success in the deep-sea, particularly near the shipwreck where nutrients from the decaying timbers entered the sediment ooze.

Decapods are dioecious. Mating in most decapods occurs shortly after molting and the sexes are attracted to each other by secreted pheromones. Precopulatory courtship is typical in most shrimps and crabs. Most female decapods brood their fertilized eggs attached to the pleopods. The cementing material is associated with the egg membrane. A free-swimming zoea larva is the typical hatching stage. The zoea larva of most crabs is easily recognized by the long, rostral spine. Megalops, the postlarval stage in crabs, is characterized by a large, flexed abdomen, and a full compliment of appendages. As is the case for many other invertebrates, there is a tendency for larval life to be shortened in decapods that inhabit cold oceans or abyssal depths.

Class Cirripedia

This class consists of the barnacles, the only epifaunal sessile group of crustaceans. Barnacles are exclusively marine and the majority of species are free living but attach themselves to rocks, shells, floating objects, and other marine animals. Barnacles have the appearance of small, shrimp-like animals, positioned upside down in a calcium carbonate case. Thoracican, or free-living, barnacles are of two types: stalked and sessile. Both types of barnacles were occasionally observed on the shipwreck site but never in large numbers. Barnacle specimens from the site were identified by Dr. Thomas E. Bowman, National Museum of Natural History, Smithsonian Institution.

Stalked barnacles have a muscular, flexible stalk (peduncle) that is attached to the substrate at one end with the major part of the body (capitulum) at the other. The capitulum consists of a surrounding mantle (carapace) which is covered by two pairs of calcareous plates (scuta and terga). The carapace margin can be pulled together for protection or it can be opened for extension of biramous feeding appendages (cirri). A large adductor muscle runs transversely between the two scuta plates and facilitates the opening and closing of the plates. A relatively large (7 cm) pedunculate barnacle, *Arcoscalpellum regium* (family Scalpellidae), was recovered from a piece of ship's timber and two specimens of a smaller (1 cm), stalked barnacle, *Megelasma subcarinata* (family Lepadidae), were brought up attached to a gorgonian coral.

Sessile barnacles have no peduncle and are considered stalkless. The attached undersurfaces of these barnacles are either membranous or calcareous. A vertical wall of plates completely rings the animal and within the wall, the upper surface of the animal is covered by an operculum, formed by a pair of movable terga and scuta plates. The wall plates overlap one another and are held together by living tissue, interlocking teeth, and partial fusion of the plates. Both stalked and sessile barnacles typically have six pairs of long, biramous thoracic cirri, used in suspension feeding, from which the class derives its name. Each branch bears many long setae with which to trap food particles.

From ancestral stalked barnacles, two principal lines are thought to have evolved which lead to the living forms found on the shipwreck: 1) scalpellids and 2) lepadids. The scalpellids are bottom dwellers and most species are found in deep water. The peduncle is covered with calcareous plates or scales, which generally increase in size toward the capitulum. The base of the capitulum is surrounded by several whorls of accessory plates. Barnacle plates of scalpellids were occasionally found in the sediment ooze recovered from the shipwreck site. The lepadids are mainly adapted for attachment to floating objects or other animals. The peduncle has remained naked and the capitulum is covered with no more than 5 basic plates: 1 carina, 2 terga, and 2 scuta. The single carinal plate forms the dorsal protective covering of most barnacles.

One of the most peculiar groups of sessile barnacles is the verrucomorphs, an asymmetrical suborder. The wall plates consist of only one tergum and scutum each, in addition to the normal carina and rostum. The other tergum and scutum form an operculum. This structure, where one set of tergum and scutum forms the lid and the other set forms the walls, give these animals a box-like appearance. Verrucomorphs are mainly deep-water species (Zullo 1982). The sessile barnacle, *Verruca* (family Verrucidae), was found attached to a lump of boiler coal at the shipwreck site.

When feeding, the paired scuta and terga plates open, and the cirri unroll and extend through the aperture to form a basket. Each side of the basket sweeps toward the other and downward, acting as a scoop net. Food particles suspended in the water are trapped by the setae. Other cirri are used to scrape the particles off and transfer them to the mouthparts. The size of food particles varies from fine phytoplankton and organic fragments to fairly large zooplankton, depending on the species of barnacle.

Most barnacles are hermaphroditic, a feature often associated with a sessile life style in many deep-sea invertebrate groups where conditions, such as sparse populations, complicate finding a mate. Eggs are released to the mantle cavity where fertilization and development proceed and from which nauplius larva are eventually expelled. The nauplius larva has a distinctive triangular, shield-shaped carapace. Generally six naupliar instars (stages between molts) are succeeded by a non-feeding cypris larva. At this stage, the entire body is enclosed within a bivalve carapace. The cypris larva is the settling stage. When a suitable substrate is located, the larva attaches itself by means of cement glands located at the base of the first pair of antennae. Following attachment, metamorphosis takes place in the following steps: cirri elongate, body undergoes flexion, and plates appear.

PHYLUM ECHINODERMATA

Echinoderms are exclusively marine animals and are largely sea-bottom dwellers. All are relatively large animals (several centimeters in diameter) that display 5-rayed (pentamerous) symmetry. The phylum contains five familiar groups: 1) sea lilies and feather stars, 2) sea stars, 3) basket stars and brittle stars, 4) sea urchins, and 5) sea cucumbers. All of the groups were well represented in the benthic community at the shipwreck of the SS *Central America*. All echinoderms have an internal skeleton composed of calcareous plates (ossicles). The skeleton is most prominent in sea urchins where it forms a rigid protection of the body and is least conspicuous in the sea cucumber where the plates are tiny and embedded within the skin. In sea stars and brittle stars, the plates articulate with one another giving these animals intermediate flexibility. Typically, the skeleton bears projecting spines or tubercles that give the body a warty or spiny appearance from which the phylum name is derived. All have a water-vascular system and small hydraulic organs (tube feet) protruding from the body. These soft structures function in locomotion, feeding, respiration, and mucus production. Echinoderms are restricted to life in salt water because they have no impervious barrier between the water circulating through their bodies and the seawater outside. Thus, in low salinity environments, there would be nothing to prevent the osmotic inflow of "fresher" water if the external salinity was below that of the body cells. Most members are dioecious but there is no known copulation. Eggs are fertilized by spermatozoa ejected into seawater.

Class Crinoidea

Crinoids (sea lilies and feather stars) are the most primitive echinoderms and the only class with upward-directed mouths. Their body consists of a small central disc which carries the main organs and a number of long feathery arms, usually ten. Primitive crinoids are anchored to the seafloor by a stalk but during evolution there has been a tendency to lose the stalks. Thus, there are two distinct kinds of living crinoids that are common at the shipwreck site—sea lilies with stalks and feather stars without. The class name refers to the superficial lily-like appearance of the stalked forms. However, feather stars (comatulids), the nonsessile free-swimming crinoids, are more common. The stalked crinoids found at the shipwreck site were drab, grayish-brown, whereas the feather stars were bright white. Specimens of both types of crinoids were recovered from the shipwreck of the *Central America*. Dr. Charles G. Messing, Oceanographic Center, Institute of Marine and Coastal Studies, Nova University, examined these specimens and provided identifications.

The sea lily body is composed of a narrow stalk and pentamerous crown. The stalks of *Porphyrocrinus* at the site ranged from 15 to 20 cm in length (Fig. 65). Video images of this crinoid showed what appeared to be a reddish-purple tethyid nudibranch perched in its crown. The nudibranch was slowly sweeping the water with its hood (buccal velum) (Boss 1982). The base of the crinoid stalk usually bears a flattened disc or root-like extensions by which the animal is fixed to the ocean floor. The bony plates, or ossicles, of the internal skeleton give the stalk its characteristically jointed appearance. In feather stars, the stalk has largely disappeared but a ring or whorl of jointed appendages (cirri) remain. These ossicle-supported structures are used for grasping the substratum when the animal comes to rest. The characteristics of the cirri (e.g., number, proportions, shape, and segments) are frequently used in classification, primarily because one species usually differs from another according to the surface favored for settlement. Those observed at the site generally preferred to perch on gorgonian corals. The pentamerous bodies of both types of crinoids at the site were drawn out into arms that forked immediately upon leaving the crown, resulting in a total of 10 arms, each 5 to 10 cm in length. Crinoids possess considerable powers of regeneration, similar to those of sea stars and brittle stars. Part or all of an arm can be cast off if seized and later regenerated. Likewise, lost pinnules and cirri can be regenerated.

The crinoid skeleton is more conspicuous than other echinoderms because the ossicles are clearly visible through the thick skin over most of the body surface. The calyx, at the center of the crown, is made up of two superimposed rings of plates, five basal and five radial, embedded in a membranous covering (tegmen). Each radial plate usually bears a forked arm. The arms are supported by a series of internal ossicles which form an endoskeleton. Each arm is lined along both edges with slender, side branches (pinnules) that are also supported by smaller ossicles. The pinnules bear tufts or tentacle-like podia and are alternately arranged giving each arm a delicate feather-like appearance. Close-up video transmission of feather stars and sea lilies on the ocean floor clearly showed much of the fine detail described above.

A nerve ring around the mouth of the crinoid controls a network of nerves which extend through channels into the ossicles of the arms, pinnules, and cirri. From the nerve ring, the movements and postures of these structures are coordinated through the activation of flexor muscles and ligaments. In a similar manner, a ring canal encircles the mouth and connects with canals which run along the upper part of the arms, above the muscles and ossicles, to form a water vascular system, essentially filled with seawater. The canals branch into each pinnule and these branch again into the podia (tube feet). Water pumped through this system of canals controlled movements of the podia much the way the hydraulic-pressure mechanism on board the submersible *Nemo* functioned to operate the manipulators.

Crinoids feed on planktonic organisms and fine organic particles suspended in seawater. Their outspread arms and pinnules form an elegant food-collecting device. Numerous, tentacle-like podia on each pinnule secrete mucus which traps small organisms and detritus. Whip-like action of the podia directs food particles to narrow, ciliated grooves that run down the pinnules between the podia. At the arm, these grooves join a larger ambulacral groove running along the upper surface of each arm toward the mouth. The cilia in this groove beat in an oral direction, carrying food down the arms, across the central disc, and into the mouth.

When feeding, crinoids at the shipwreck site unfolded their arms much like an opened fan. The outspread pinnules and erect podia formed a dense capturing net. These arms were positioned across the water current, thereby providing the greatest possible surface for trapping flowing food particles. Because the free-swimming feather stars are capable of changing their location at will, they enjoy an advantage over the sessile, stalked forms. Locations with moderate flow are best, strong enough to sweep the necessary food particles along but not so violent as to dislodge the animal or clog the net with unwanted debris. Since water currents play an important role in the feeding strategy of crinoids, the gentle currents (about 10 cm/s) which flowed around and over the projections of the *Central America* shipwreck had produced a favorable habitat as evidenced by the abundance of these animals. A common perch for the comatulid, *Caryometra alope*, at the wreck site was on the axial skeleton of the gorgonian coral, *Chrysogorgia* (Fig. 105). The much less common stalked

FIGURE 105. A comatulid crinoid (*Caryometra alope*) is attached to an atrophied stalk of a golden coral (*Chrysogorgia* new species). A living golden coral is attached to collapsed timbers of the *Central America*.

crinoid, *Porphyrocrinus,* occurred in lower areas where a veneer of sediment blanketed the wreckage. These animals were often attached to a lump of coal (Fig. 65).

Sessile sea lilies are limited to bending movements of the stalk and flexion of the arms. The stalkless comatulids, however, are free-moving and capable of crawling, tumbling, and swimming because of their articulated arms. All three types of movement were observed at the shipwreck site. On a few occasions, the submersible disturbed a resting feather star and the control room team was treated to the spectacular sight of a crinoid swim. The swimming motion is achieved by forceful, yet very graceful, up and down beating of the 10 arms. During the whip-like downbeat, the pinnules on the arms are rigid, creating a broad paddle surface which produces a forceful lift for the animal. Whereas, on the upsweep beat, the pinnules are pressed against the arm to reduce the frictional force of lifting the arms (Fechter 1984). In adjacent arms, the swimming motions are opposed. Thus, in the ten-armed feather star, *Caryometra alope*, arms 1, 3, 5, 7, and 9 were lifted at once.

When *Caryometra* first lifted from its perch, the swimming motions were quite forceful at a rate approaching 100 beats per minute. This exertion was only maintained for about 10 seconds and once the crinoid was free from obstructions, it switched to a slower and more measured pace (60 to 70 beats per minute). Feather stars were never observed swimming for prolonged periods; the longest was about 90 seconds. Each beat moved the animal approximately one arm's length in a vertical direction. Once the animal had risen to a height of one or two meters above the bottom, it lifted all of its arms in a half-raised "parachute" fashion and drift slowly to the ocean floor in search of a new place to settle, perhaps a meter away from its original position.

Crinoids are dioecious with many separate gonads located in pinnules along the inner half of the arms. When the eggs or sperm are mature, spawning takes place by rupture of the pinnule walls and fertilization takes place in seawater. Brooding in chambers on the arms is displayed by some cold-water species (Barnes 1987) and may have been a strategy used by crinoids at the shipwreck site but it was not observed. Alternatively, the egg can have a high yolk content and it develops into a non-feeding larva (vitellarium), encircled with bands of cilia and sensory tufts. After several days of free-swimming existence the vitellarium settles and attaches itself to the bottom. There, metamorphosis results in the formation of a minute, stalked, sessile crinoid (for comatulids this is the pentacrinoid stage). Juvenile feather stars soon break away from the attachment stalk and take up an independent life.

Class Stelleroidea

This class contains those star-shaped, free-moving echinoderms in which the body is composed of arms projecting from a central disc. The class is divided into two prominent groups: the sea stars (subclass Asteroidea) and the brittle or serpent stars (subclass Ophiuroidea).

Subclass Asteroidea. Sea stars are characterized by a pliable body but unlike the upward oriented crinoids, the oral surface faces the substratum. The main trunk of the body is disc-shaped with five or more unbranched arms projecting from it. Sea stars with five, six, and 11 to 14 arms were observed on the shipwreck of the SS *Central America*. The arms are not set off from the central disc, except in the family Brisingidae, which was present at the shipwreck site. From the mouth, located in the center of the underside of the disc, a wide furrow (ambulacral groove) extends radially into each arm. Each furrow contains two to four rows of small podia. The margins of the furrows are guarded by movable spines that are capable of closing over the grooves. The aboral surface has a button-like structure (madreporite) which functions as a sieve plate to maintain the proper water balance in the water-vascular system. The body may either appear smooth or bear spines, tubercles, or ridges. The outer surface is covered by an epidermis which contains mucus and ciliated sensory cells. Detritus that falls on the body is trapped in the mucus and is then swept away by the cilia or directed toward the mouth as was observed at the shipwreck site. Below the skin, a thick layer of connective tissues holds ossicles which form a skeletal system. Many sea stars bear small, jawlike appendages (pedicellariae) that are used for protection against small animals or larvae that may settle on their bodies. The pedicellaria are of two types: stalked and sessile. The stalked ones consist of a fleshy pedestal surmounted by a jawlike apparatus composed of three moveable ossicles that are arranged to form minute scissors. The sessile type are composed of two or more short, moveable spines on the same or adjacent ossicles that articulate against one another to form a small pincer.

Three orders of asteroids were observed and sampled from the wreck site: Paxillosida, Spinulosida, and Forcipulata. Dr. David L. Pawson and Cynthia G. Ahearn, National Museum of Natural History, Smithsonian Institution, and John E. Miller, Harbor Branch Oceanographic Institution, examined photographs and specimens of sea stars and provided identifications and life history information. All the abyssal sea stars were noticeably flattened, with flexible bodies that ranged in shape from pentagonal to stellate.

Paxillosids, such as the burrowing sea star *Plutonaster* (family Astropectinidae), have relatively short arms and a broad central region so that the entire animal forms a pentagon. Special modifications for burrowing include: 1) an aboral surface that bears special ossicles (paxillae) that raise above the body surface and extend outward like a parasol, 2) moveable spines that crown the raised part of the ossicle, 3) network of adjacent paxillae that hold back the sediment, creating water passages for respiratory and feeding currents, and 4) sessile type pedicellariae. A specimen of *Plutonaster efflorescens* was sampled with one of *Nemo*'s manipulators a few centimeters below the sediment surface adjacent to the collapsed hull of the ship. The resiliency of the body was demonstrated when the jaws of the manipulator, which had a closing force of about 70 kg, were applied in a pincer-like action to collect the specimen. Several hours later, when *Nemo* returned to the deck of the R/V *Arctic Discoverer,* inspection of the specimen indicated no evidence of physical damage (Fig. 106). The individual had a major radius dimension (center of disc to tip of arm) of 40 mm. The coalesced paxillae accounted for a smooth appearance of the body. The specimen of *Plutonaster efflorescens* lacked suckers on the tube feet but possessed distinct marginal plates and spines. The pronounced marginal spines distinguished this species from *Plutonaster agassizi agassizi* which has a smoother margin (Clark and Downey 1992). The known range of *P. a. agassizi* encompassed the shipwreck site, whereas *P. efflorescens* is not known north of the Caribbean Sea; thus, this observation represents a range extension of nearly 1,000 km. Presumably these sea stars fed on the benthic infauna (meiofauna) which also lived in the sediment ooze surrounding the shipwreck.

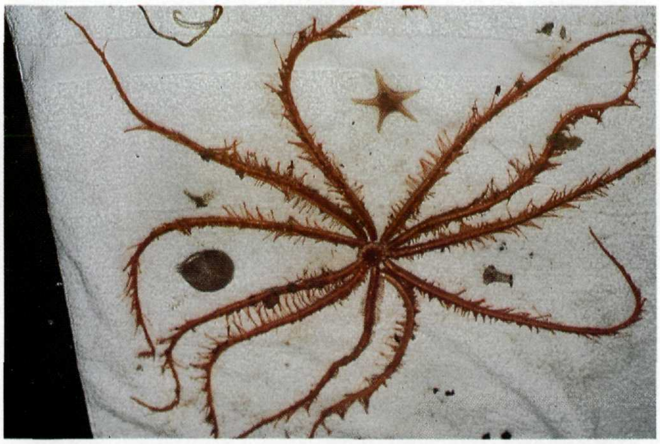


FIGURE 106. Brisingid sea star (*Brisinga cricophora*) recovered from the shipwreck of the *Central America* (see Figs. 52, 109 for same specimen). On the ascent to the surface, the sea star cast off all but two arms from the central disc (the other nine arms have been placed in their approximate original condition). A five-armed, burrowing sea star (*Plutonaster efflorescens*), at top center, a heart urchin (*Palaeobrissus hilgardi*), at left center, and a stony coral (*Desmophyllum cristagalli*), at right center, were all collected from the same location on the shipwreck.

Spinulosids do not have conspicuous marginal plates but the tube feet are suckered. The aboral surface is covered with low spines and they bear no pedicellariae. Within this order, the family Echinasteridae was represented by the species *Henricia antillarum* on the shipwreck site. The skeleton of this species is reticulated in a web-like network with small spines in groups along ridges and the podia have suckers which occur in double rows within v-shaped, ambulacral grooves along the underside of each arm. One individual of this species was photographed on the timbers of the shipwreck in 1988 and was later identified by Dr. David L. Pawson, National Museum of Natural History, Smithsonian Institution. It was pale pink in color and had a small central disc and five cylindroid arms that were somewhat constricted where they joined the disc.

The order Forcipulata, characterized by pedicellariae composed of a short stalk, was represented by two families of sea stars on the shipwreck site: Pedicellasteridae and Brisingidae. The pedicellasterids have a disc of moderate size continued broadly into rounded, tapering arms of moderate length, five or six in number, and a warty surface consisting of a network of pedicellariae. In September 1989 two pedicellasterids, each with six arms, were captured in a modified minnow trap baited with beef. Also collected in the same trap were four galatheid crabs, genus *Munidopsis* (Figs. 56, 107). Cynthia G. Ahearn, National Museum of Natural History, Smithsonian Institution, identified these specimens, and an additional one recovered in 1991, as *Ampheraster alaminos.* The key features that were diagnostic of this species included a dense covering of pedicellariae, longer inframarginal spines, and six arms.

Members of the family Brisingidae are confined to deep water and most of the genera have very long, slender (sometimes needle-like), single marginal spines. Brisingids are multi-armed (usually 11 to 14) and resemble brittle stars by having very narrow arms and a small, round central disc (Downey 1986). The joints linking the arms to the disc are easily broken. Most brisingids are very fragile and in some species only the arms have been collected, as no discs survived the rough treatment of trawling (Clark 1977). At the shipwreck, the serpentine arms of *Brisinga cricophora* attained a length of nearly 30 cm but the disc was scarcely more than 3 cm in diameter (Figs. 108, 109, 110). This was a handsome species of a brilliant, reddish-orange color. Mortensen (1927) commented about *Brisinga,* "when complete, probably the most magnificent of all sea stars." Although all three specimens recovered from the shipwreck exhibited the characteristics of *B. cricophora,* such as 11 arms, orange color, and a small disc (Clark and Downey 1992), another group of somewhat larger brisingids were prominent in photographs. This second group, which had 12 to 14 arms, a heavier appearing disc, and more coarsely ribbed arms, more closely matched the characteristics of *B. costata* (Figs. 111, 112). The known range and depth for this species includes the shipwreck site, whereas the deepest previous specimen of *B. cricophora* was collected at 1,340 m (Clark and Downey 1992).

Brisingid sea stars are of particular interest for a number of reasons. They were very abundant at the site—the estimated population on the shipwreck was at least 300 individuals. The female was quite large (40 to 50 cm across) and bright orange, whereas, individuals believed to be males of the same species were considerably smaller (10 to 20 cm), less abundant, and white. Also, they appeared to exhibit a form of mating behavior (Figs. 66, 112).

Hyman (1955) points out that the sexes usually cannot be distinguished externally except when the females are brooding or when ripe gonads influence body coloration (testes are generally pale white, ovaries either pink or orange). The tropical Indo-Pacific genus *Archaster* is known to practice a sort of copulation (Clark 1977). During the breeding season, they are found in sexual pairs, a male on top of a female, with

FIGURE 107. Gold specie bars and gold coins on the shipwreck provide habitat for macroinvertebrate animals such as the galatheid crab, *Munidopsis crassa*, and the 6-armed sea star, *Ampheraster alaminos*.

their arms alternating. The males of this genus are only slightly smaller than the females. Sperm is probably shed directly into the water, as with other sea stars, but there is a much better chance that most of the eggs will be fertilized than with the haphazard shedding of most sea stars and other echinoderms.

Marked sexual dimorphism is unknown for asteroids and mating behavior is rare (Delavault 1966, Hyman 1955). However, the deep-sea brisingid sea star (*Brisinga cricophora*), which was found in abundance at the shipwreck, was observed "copulating" on several occasions. In each case, a conspicuous orange female was seen on top of what is presumed to have been a diminutive white male. The spawning process lasted for several days and took place on elevated surfaces, such as the rim of the iron side wheel or a stack of gold coins. Repetitive dives to the same locations on the shipwreck over a period of several weeks provided an opportunity to observe the courtship and mating behavior of these sea stars (slow movements were not obvious on a single dive). The ironworks of the wreck appeared to be a favored location for these animals. Approximately 50 individuals were counted on the rims of the port side wheel, including a mating pair with a smaller, white-colored male under a larger, orange-colored female.

FIGURE 108. Female brisingid sea star (*Brisinga cricophora*) on pteropod ooze sediment within hull of *Central America* shipwreck. A quillworm tube (*Hyalinoecia artifex*) rests on the ooze at the lower right of the photograph.

Eventually, the entire courtship process was observed within the wreckage. Apparently, a wooden crate containing some 300 double-eagle gold coins had deteriorated over time, probably because of wood-borer activity which was prevalent on recovered pieces of wood, leaving the coins standing as a tower. During a dive in July 1989, a male *Brisinga* (small, white but similar in morphology to the larger orange females) was noted alongside the tower while a female was situated a few

FIGURE 109. A female brisingid sea star (*Brisinga cricophora*) is draped over timbers on the *Central America* shipwreck. This sea star typically has 11 arms lined with a double row of pinnules for gathering suspended food particles. Near the center of the photograph an undescribed species of gorgonian coral in the genus *Chrysogorgia* is gently bent by the current. A small sea anemone (*Chondrophellia coronata*?) is on the timber below the sea star and a hexactinellid sponge (*Farrea* new species) is located between them. Another glass sponge (*Rhabdodictym* sp.) rests on top of the timber to the right of the coral. The curved timber behind the sea star is a structural part of the ship known as a hanging knee. All of the wood shows evidence of being invaded by wood-boring bivalves.

meters away on a pile of gold bars. The male had a major radius length of about 120 mm while the female's arms approached 300 mm. By the next dive, the male had climbed to the top and then positioned himself halfway down the tower where he remained throughout the courtship. Using *Nemo*'s manipulator, the female was gently lifted from her position but she did not immediately move away. The following dive revealed that she had moved onto the coin tower with her central disc squarely over the top and her 11 arms draped down the sides, some in contact with the male. By the next dive, mating appeared to have begun as the female moved down the side of the tower and placed her disc on top of the male's disc. The pair remained in this position for three days and then the female retreated from the tower. On the following dive, an aluminum shell was placed over the tower and injected with a silicon solution and a hardening catalyst, encasing the male against the tower. A day later, the injected material had solidified to a consistency of stiff, foam rubber and the box containing the coin tower and the encapsulated male *Brisinga* were recovered from the ocean floor.

Several investigations have indicated bioluminescence in the deep-sea family Brisingidae (Millott 1966). *Brisinga endecacenmos*, *B. coronata* and *Freyella* sp. are among the taxa described as luminous. Because of the difficulties of *in-situ* deep-ocean observations, luminescence has largely been inferred from the possession of gland cells resembling those of luminous ophiuroids. The deep-ocean submersible, *Nemo*, provided an excellent opportunity to determine the presence of bioluminescent brisingids on the *Central America* site but such experiments have yet to be undertaken. However, high-level photographs taken some 20 m above the site, consistently revealed bright images of both brisingid sea stars and galatheid crabs even under low light conditions.

Most asteroids are scavengers and carnivores, feeding on invertebrates, particularly gastropods, bivalves, crustaceans, polychaetes, and other echinoderms. They appear to detect and locate food from substances released into the water by their prey. Some sea stars that live on soft bottoms can locate buried prey in this way and then dig down into the sediment to reach it. Others can catch small fish, amphipods, and crabs with their pedicellariae when the prey comes to rest against the aboral surface of the sea star. Still others feed on sessile animals, such as sponges, sea anemones, and polyps of hydroids and corals. Predatory species with short arms swallow the prey entirely, whereas, those with long arms evert their stomach and partially digest the prey outside

FIGURE 110. A female brisingid sea star (*Brisinga cricophora*) rests atop a pile of gold bars on the shipwreck of the *Central America*. A smaller male of the same species can be seen on a tower of gold coins at the upper left. A white galatheid crab (*Munidopsis crassa*) can be seen at top left and a 6-armed sea star (*Ampheraster alaminos*) at lower left.

the body. Sea stars that prey on bivalve molluscs slide their stomach between the valves while others use their everted stomach like a mop to remove organic material from submerged surfaces.

In the deep sea, a preferred strategy may be that of suspension feeding. Plankton and detritus that come in contact with the body surface are trapped in mucus and then swept toward the oral surface by the epidermal cilia. On reaching the ambulacral grooves, on the underside of the arms, the food-laden masses are carried by ciliary currents to the mouth. At the shipwreck site, large brisingid sea stars were often observed with their 11 to 14 arms raised in a basket-like fashion (Fig. 113). Presumably these animals were collecting organic debris carried by the gentle bottom currents. However, some deep-sea asteroid species are largely carnivorous, preying on worms, foraminiferans, bivalves, and other echinoderms (Marshall 1979).

The water-vascular system is well developed in sea stars and functions as a means of locomotion. The system consists of a series of canals, open to the sea at the madreporite, through which water trickles to a radial canal in each arm and eventually to numerous tube feet via lateral canals. Each lateral canal has a valve and terminates in a muscular bulb (ampulla) above the tube foot. When the ampulla contracts, the water in the bulb is prevented by the valve from flowing back into the radial canal and is forced into the tube foot. This extends the foot which attaches itself to the underlying substrate by mucus or a sucker. Next, the muscles of the tube foot contract, shortening it and forcing the water back into the ampulla, which pulls the animal in the direction of the original extension. Hundreds of these tube feet, working in unison, effectively move the sea star forward. In general, even when disturbed, sea stars move very slowly and they tend to remain within a relatively confined area. Repeated dives on the same location on the wreck site indicated very little movement of individuals over a several month period and in some cases from year to year.

Most asteroids are dioecious with gonads in each arm. Gonads vary greatly in size depending on the proximity to the time of spawning (when filled with eggs or sperm they almost completely fill each of the arms). In the majority of sea stars, the eggs and sperm are shed freely into the seawater, where fertilization takes place. The presence of eggs or sperm in the seawater acts as a stimulant for the shedding of sex cells by individuals of the opposite sex. Some cold-water species from the Arctic and Antarctic are known to brood large yolky eggs in depressions in the disc or in pouches formed by spines between the bases of the arms where development is direct with no larval or planktonic stage (Barnes 1987). However, in most sea stars, the fertilized eggs develop into planktonic ovoid larvae which swim by means of minute cilia arranged in encircling bands. The length of larval life varies not only from species to species but also with prevailing environmental conditions and spawning is often suppressed in less favorable seasons (Clark 1977). In the deep sea, where seasonality is much less pronounced, the abundance of food may be the primary factor in stimulating reproduction.

Autotomy, the process whereby animals may break their body portions, is exhibited in sea stars by a reflex separation of one or more of the arms. Typically, the arm to be detached is anchored to the substrate by its tube feet while the rest of the animal moves away. The separation is generally at the edge of the central disc. In contrast, *Brisinga* can autotomize arms at any point at which they are stimulated. When they are hurt or held in unfavorable conditions, brisingid arms need not be seated on substrate for separation to take place. For example, *Brisinga* will often autotomize all its arms on being brought to the surface, yielding only the small disc and a number of isolated arms (Swan 1966).

In September 1989, while sampling a hexactinellid sponge, a large orange brisingid sea star was also collected when it remained attached to the piece of ship's timber that contained the sponge. The video images clearly showed the release of one of the 11 arms. Interestingly, the released arm became entangled with the others and the entire animal was safely placed in the storage compartment of the submersible. During the 2-hr ascent to the ocean surface, the animal apparently experienced considerable stress for when the compartment was opened on the deck of the research vessel, only two arms remained attached to the central disc (Figs. 52, 106). This specimen was later identified by John E. Miller, Harbor Branch Oceanographic Institution, as a female *Brisinga cricophora*. In contrast, in September 1991 another female *Brisinga* was recovered but in this case, all of the arms remained attached to the disc but several of the arms were less than full length.

Asteroids exhibit considerable powers of regeneration. Any part of the arm can be regenerated, as well as, damaged or destroyed sections of the central disc. There was abundant evidence on the shipwreck that regeneration of autotomized arms of brisingid starfishes took place (e.g., animals with one or more arms shorter than the rest, presumably not yet fully regrown). Hyman

FIGURE 111. A 14-armed brisingid sea star (*Brisinga costata*) on the port side wheel of the SS *Central America*. Note how the arms of the sea star and a gorgonian coral are being forced to the left (southwest) by the bottom current and that the rusticle grown on the underside of the side wheel is bent in the same direction.

FIGURE 112. Possible copulation behavior of brisingid sea stars on the ironworks of SS *Central America*. A large 14-armed female sea star (*Brisinga costata*) is resting on top of a smaller male. The metallic sphere at bottom center is thought to be a fly-ball governor.

(1955) noted that in all species of sea star tested, the separated arms were readily regenerated but that the process was relatively slow. At the extreme environmental conditions of the *Central America* shipwreck, where metabolic rates are obviously quite low, regeneration may require a protracted period of time.

Subclass Ophiuroidea. Video transmissions from the ocean floor surrounding the shipwreck revealed occasional serpent or brittle stars snaking their way over the sediment ooze. Many of these ophiuroids had large (over 3 cm diameter), round to pentagonal central discs from which five elongated arms radiated. In contrast to most of the sea stars at the site, *Brisinga* being the exception, the central discs of the ophiuroids were definitely set off from the arms. Vertebra-shaped ossicles occupied the interior of each arm and were arranged linearly from the central disc out to the narrow tip. The ends of the vertebral ossicles bore sockets and nodes which articulated with adjacent ossicles. Each arm was covered with four rows of calcareous plates, or shields, which overlapped and gave the arms the appearance of being jointed; short spines projected from between the plates.

Two species of brittle stars were observed and collected at the shipwreck site, *Bathypectinura heros* and *Ophiomusium lymani* (Figs. 114, 115). These species are placed in the families Ophiodermatidae and Ophiuridae, respectively (Fell 1982). Both provided specimens that ranged from about 10 to 30 cm armspread. The largest was an *Ophiomusium* with a central disc diameter of 3.5 cm.

Specimens of *Bathypectinura* had a very granular, purple-colored central disc. The arms were fused with the disc laterally at the margin, were stoutest at the base, and exhibited three or four spines at each plate contact. A single papilla was present at the apex of each of the five triangular jaw structures and the jaw margins had numerous papillae. By contrast, specimens of *Ophiomusium* had a smoother, orange-colored, central disc covered with a thick plate and 10 very pronounced radial shields. The arms were similar to *Bathypectinura*, being long and stout at the base and conspicuously tapered. The arm spines were small and the mouth papillae formed a continuous series. *Ophiomusium lymani* is thought to be the most abundant and widely distributed abyssal ophiuroid (Fell 1982).

Ophiuroids were the most errant echinoderms at the shipwreck site with the possible exception of swimming feather stars. Their tube feet lacked suction discs and thus played no major role in locomotion; rather, contraction of muscles in each of the flexible, jointed arms provided the primary means of movement. The articulation of the vertebral ossicles allowed great lateral mobility of the arms but only limited vertical movement.

Typically, the brittle stars moved fairly rapidly over the bottom by extending one arm ahead, trailing two behind, and using the remaining two as oar-like appendages

FIGURE 113. Gold bars and coins on the collapsed timbers of the SS *Central America* are substrate for deep-ocean biological oasis. Gorgonian corals (*Chrysogorgia* new species), comatulid crinoids (*Caryometra alope*), pedunculate barnacles (*Megelasma subcarinata*), hexactinellid sponges (*Rhabdodictym* sp. and *Farrea* sp.), a brisingid sea star (*Brisinga cricophora*), and small scyphozoans (*Stephanoscyphus* sp.) have colonized the gold. The brisingid sea star has its arms in a raised position to capture suspended organic particles. Calcareous tubes of wood-boring bivalves can be seen on the lower left side of the photograph.

to pull themselves over the sediment. During this movement, the disc was usually held above the bottom and the two lateral arms "rowed" the animal forward in pulses. They seemed to show no preference for which arm was the leading member. Juvenile ophiurids were observed swimming in the same position, using the two side arms as fins. Both types of motion were captured on videotape as the submersible *Nemo* cruised several meters over the bottom on reconnaissance surveys. Juveniles were also observed high on the shipwreck, e.g., the elevated side wheels, where the spines along the arms seemed to be assisting them in clinging to the rusting iron.

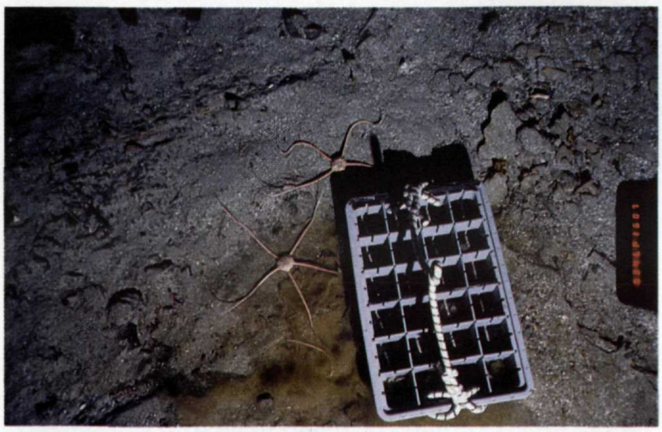


FIGURE 114. Brittle stars (*Ophiomusium lymani*) snake their way over the seabed near a collection tray at the SS *Central America* shipwreck site.

Most brittle stars appeared to have a retiring nature and the observed movements were often avoidance responses. Traumatic loss of arms may have been commonplace at the shipwreck site based on observations of varying lengths of ophiuroid arms which were presumably in various stages of regeneration.

Although brittle stars were occasionally seen on the foraminiferal ooze surrounding the shipwreck, only rarely, if ever, were they observed within the hull area until the deployment of a bait experiment. Within a few hours after placing 50 kg of fish carcasses and several trays of fish meal on the ocean floor at the shipwreck, numerous brittle stars invaded the site. Underwater photographs from previous deep-sea investigations reveal high population densities of ophiuroids when conditions are favorable (Barnes 1987), particularly an abundant supply of food. At the bait experiment, the brittle star density eventually reached several per square meter and a number of the animals entered the trays. The most common ophiuroid to move in was *Ophiomusium lymani*. Photographs taken by Owen (1967) at a depth of 2,086 m off Woods Hole, MA, show a similar invasion of this species. Movement of these individuals seemed more deliberate than those observed outside the hull. For example, video transmissions clearly showed that once the leading arm pointed, each of the other four arms was used for propulsion.

FIGURE 115. Specimens of a sea star (*Brisinga cricophora*) and brittle stars (*Ophiomusium lymani*) retrieved from the shipwreck site by the submersible *Nemo*. Note the various stages of arm regeneration on the *Brisinga* specimen. Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University, examines specimens on board the R/V *Arctic Discoverer*.

Ophiuroids in the deep sea are opportunistic omnivores, using several feeding strategies; they are carnivores, scavengers, deposit feeders, or filter feeders (Gage and Tyler 1991). One species may use several feeding modes but one usually dominates. Carnivorous brittle stars feed largely on polychaetes, molluscs, and small crustaceans. Food is captured and brought to the mouth by looping the arms. Scavenging was observed to take place in a similar way on bait that had been set on the ocean floor. Because of the amount of brown algae (*Sargassum* spp.) that was observed drifting down to the site and the relatively high organic content of the sediment at the shipwreck, browsing and deposit feeding were probable strategies employed by brittle stars. Filter feeding by ophiuroids was not be observed at the shipwreck. The species found at the shipwreck had limited vertical arm mobility and they lacked long spines; thus, lifting the arms and waving them about in the water as filtration nets would have been an unlikely strategy.

Pressure is not known to exert any influence on ophiuroids. There is no gaseous component in the body and tissue fluids are subjected to the same compression as the surrounding seawater. Consequently, when specimens of brittle stars were brought to the surface from the shipwreck site, they appeared not to have suffered any decompression injury. Fell (1966) reported that ophiuroids recovered from the deep sea remain active in an aquarium at sea level provided the environment is maintained at the same temperature as that of the sea bottom.

Most ophiuroids are dioecious but hermaphroditic species are not uncommon. When the gonads are ripe, eggs or sperm are carried out of the body by the same cilia-created water ventilating current that facilitates gas exchange. Fertilization and development take place in seawater for many species but some species brood a small number of eggs internally until the juvenile stage is reached. In nonbrooding brittle stars, metamorphosis takes place while the larva is free swimming, followed by settlement to the bottom. Development to this point, where brittle stars begin a benthic life, takes several weeks for nonbrooding species and several months for those that brood their young (Hendler 1975).

Class Echinoidea

The echinoids include free-moving sea urchins, sand dollars, and heart urchins. Sea urchins are globular animals that are flattened on the bottom. Their soft bodies are enclosed in a thin, brittle test covered with moveable spines. The test is composed of closely fitting plates which bear tubercles that form "ball and socket" joints at the base of the moveable spines. In addition to the spines, five sets of podia protrude through the test. Urchins move by a coordinated use of both their feet and spines. The mouth, which opens on the underside of the body, is equipped with a complex feeding apparatus known as "Aristotle's lantern." This apparatus consists of some 40 skeletal plates, intricately interbound with 60 muscles and connective tissues, on which are located five hard and constantly growing teeth. Urchins can rasp encrusting organisms from the surface of the substrate over which they are traveling by moving the teeth up and down in relation to the mouth and by moving them toward and away from each other.

Two basic types of body structure are found in this class: radial (regular echinoids, e.g., sea urchins) and bilateral (irregular echinoid, e.g., sand dollars and heart urchins). Regular urchins have more or less spherical bodies armed with long, moveable spines. Whereas, irregular ones are oval, or flattened, and their bodies are adapted for burrowing with numerous small spines used in locomotion and in keeping sediment off the body surface. Both types of echinoids were represented at the shipwreck site.

Regular urchins observed at the site ranged from about four to 12 cm and exhibited a variety of colors, including black, purple, grayish-brown, and white. The bodies of sea urchins are constructed in the form of two hemispheres (aboral and oral) with structures arranged around an axis through the poles. The underside (oral) pole is the location of the mouth which is surrounded by five pairs of bushy gills that are active in gas exchange. The anus is located at the aboral pole. The test has 10 radial parts converging at the two poles; five sections contain tube feet (ambulacral areas) and five are devoid of podia (interambulacral areas). The moveable spines are more or less symmetrically set on both areas. They are longest around the equator and shortest at the poles. Small, jawlike pedicellaria, on long stalks, are also located all over the body surface.

The majority of sea urchins are grazers, scraping the surface on which they live. Those that live on soft bottoms in the deep sea are deposit feeders, consuming minute organic material in the sediment ooze. Sea urchins are adapted for life on hard and soft bottoms, with spines and podia used for locomotion. Tube feet function in the same way as those of sea stars, while spines are used for pushing and raising the oral surface off the bottom. Sea urchins can move in any direction. Movement of sea urchins is closely related to feeding activity; in general, the sparser the food supply, the greater the movement.

Members of two families of regular echinoids were observed and photographed at the site. They included the small white *Echinus* of the family Echinidae and the larger black *Araeosoma* and *Phormosoma* of the family Echinothuridae. *Echinus* is a deposit feeder that excavates sizable pits or burrows in the sediment surface (Gage and Tyler 1991). Many such pits were observed in the sediment ooze surrounding the shipwreck. The latter family is composed of cushion-shaped urchins that have tests made of imbricating plates which maintain the animal's shape by actively pumping water into the body cavity; thus the highly flexible tests collapse when removed from the water (Fell 1982). *Phormosoma* has been reported in dense aggregations on the abyssal seabed off New England (Grassle et al. 1975) but only isolated individuals were noted at the shipwreck site, even when the ocean floor was baited with 50 kg of fish carcasses and periodically scanned for a one-month period. Those echinothuroids that were observed on the site appeared to live on the soft sediment and supported themselves by long, delicate, "hoofed" oral spines. The hoofs were white and club-shaped, while the spines were black. A number of these hoofed spines were recovered in sediment samples and were examined by Cynthia G. Ahearn, National Museum of Natural History, Smithsonian Institution, who noted that they resembled those of *Araeosoma belli*. Videotape images of hoofed echinoids showed that these animals moved rapidly over the soft bottom without sinking into the sediment.

Irregular echinoids are somewhat flattened and elongated so that the mouth is located toward the anterior end and the anus at the posterior, giving them a secondary bilateral symmetry. Conspicuous ambulacral grooves (petaloids), each shaped like a petal, radiate from the center of the aboral surface. Irregular echinoids are adapted for burrowing in sand by action of the spines. Heart urchins burrow forward into sediment by inclining their anterior end downward and moving grains with especially modified, paddle-shaped spines. Small spines form a dense covering over the body but tube feet are degenerate or absent around the circumference of the body and are functional only on the oral and aboral surfaces. All irregular urchins are selective deposit feeders, consuming organic material in the sediment in which they burrow. Heart urchins possess oral podia that are specialized for obtaining food particles from the interior surfaces of their burrows.

One of the most common echinoids at the wreck site was the heart urchin, *Palaeobrissus hilgardi* (Fig. 106). These dark purple to grayish-brown urchins have been described as the principal ploughers of the deep seafloor (Marshall 1979). Their broad meandering tracks were evident in the foraminiferal ooze surrounding the shipwreck. Presumably the brush-like podia around the mouth pick up organic particles in the sediment and convey them to the mouth via converging tracts of cilia. A specimen of *Palaeobrissus hilgardi* was collected in the sediment adjacent to the shipwreck in September 1989. Dr. David L. Pawson, National Museum of Natural History, Smithsonian Institution, examined the specimen and provided the identification.

All echinoids are dioecious. Generally, sperm and eggs are shed into the seawater where fertilization takes place. Brooding is displayed in some cold-water sea urchins and heart urchins. Sea urchins use their spines to hold their eggs while heart urchins retain them in the deep grooves of the petaloids. A free swimming echinopluteus larva forms in seawater and eventually sinks to the bottom. There is no attachment to the bottom, as in sea stars, and metamorphosis is rapid (minutes) with the young urchins being no larger than 1 mm (Barnes 1987).

Class Holothuroidea

Holothurians are elongated, cucumber-shaped echinoderms but like echinoids, their body is not drawn out into arms. The skeleton is reduced to microscopic ossicles (sclerites), embedded in their leathery skin, which give the body great flexibility. Sea cucumbers are primarily deposit- or suspension-feeders. The tube feet around the mouth have been modified to a circle of sticky tentacles which vary in size from species to species depending on the size of the detritus particles on which they feed (Haywood and Wells 1989). The mouth is surrounded by 10 to 30 tentacles which are retractable by pulling the adjacent body wall over them. The anus is located at the tip of the body at the opposite end from the mouth. The body shape varies from almost spherical to long and wormlike. Holothurians lie with one side of the body (sole) against the substrate. The sole commonly contains three rows of podia used for locomotion. The water-vascular system of holothurians is basically the same as that of other echinoderms. Members of the order Apodida completely lack podia, including the most prominent holothurian observed on the site, *Chiridota*.

Sea cucumbers are sluggish animals that lie on the ocean floor or burrow into the sediment. Forms with podia creep along on the sole with their tube feet functioning as they do for sea stars. Rolling is accomplished by twisting the mouth end around until the podia can grasp the substrate. Burrowing species, which normally lack podia, move through the sediment by contraction of longitudinal and circular muscle layers of the body. The tentacles also aid by pushing away sediment particles.

Sea cucumbers were common members of the benthic community on the SS *Central America* shipwreck (Fig. 60). Typically these were bulbous or elongated, worm-shaped animals with a purple to bluish-gray coloration. Tube feet did not appear obvious and locomotion seemed to be achieved primarily by contraction of the body. In one individual in the genus *Chiridota*, the body was extended to over 30 cm forming a long, narrow cylinder.

Most deep-sea holothurians are deposit feeders living in or on the ocean sediment. They normally stretch out their branched tentacles and sweep them over the bottom, trapping particulate material on adhesive pads. However, on the site, sea cucumbers frequently occurred on the timbers of the wreck and were less commonly observed on the sediment ooze. One of these, a new species in the genus *Chiridota* identified by Dr. David L. Pawson, National Museum of Natural History, Smithsonian Institution, was a purple colored animal with dendritic-shaped pads at the end of its tentacles. *Chiridota* used these tentacles to capture suspended particles or to grasp those which came to rest on the timbers. Video transmissions clearly showed the feeding behavior. Feeding was facilitated by a ring of approximately 12 tentacles. Detritus on the timbers and organic matter in the sediment ooze were major food items. One at a time, the tentacles were stuffed into the pharynx and the adhering food particles were wiped off as the tentacles were pulled out of the mouth. The animals were observed placing rather sizable particles (up to 1 mm) in their mouths, some of which were rejected and fell to the ocean floor.

Members of two other families were also observed on the shipwreck sites. The family Synallactidae, comprised of deep-water holothurians, had one representative on the site, *Pseudostichopus mollis.* A specimen of this species was recovered from the sediment ooze which had accumulated within the shipwreck. This animal was relatively nondescript, elliptically-shaped, flattened, and possessed a distinct anal notch. This species is devoid of ossicles which accounts for its relative lack of form. Identification of the specimen was confirmed by Cynthia G. Ahearn, National Museum of Natural History, Smithsonian Institution. In contrast, members of the family Deimatidae possess imbedded calcareous plates and two rows of "walking" podia that give them a rather bizarre appearance (Hyman 1955). Deep-sea photographs taken at Site H, in areas of coal piles and collapsed timbers, showed footed creatures crawling over the debris. Presumably they were holothurians of the genus *Deima.*

Pawson (1966) notes that there is no evidence to suggest that pressure has any effect on the ecology or vertical distribution of holothurians because they are found at all depths to 10,000 m. He concluded that temperature plays a more important role in limiting their distribution. When attacked or as a result of chemical changes in the environment, some sea cucumbers can discharge their digestive tract (evisceration) or sticky threads (tubules of Cuvier) through the anus and direct them toward the intruder. The expelled organs are quickly regenerated.

Most holothurians are dioecious, casting eggs and sperm into the seawater where fertilization takes place. Brooding is known in some cold-water forms. During spawning, the eggs are caught by the tentacles and transferred to the sole for incubation. Except in brooding species, development takes place externally in the seawater, the embryo being planktonic. Several larval stages occur and eventually the young sea cucumber settles to the ocean floor and assumes the adult mode of life.

MINOR PHYLA

Phylum Ctenophora

Ctenophores comprise a small phylum of marine animals that are commonly known as comb jellies. These delicate creatures float in the ocean, mostly near the surface and along the shores but a few types inhabit the deep sea. They are thought to be related to the cnidarians and may have evolved from a medusoid form without nematocysts. The more primitive ctenophores are spherical or ovoid in shape, and typically less than 5 cm in diameter. Other shapes include double lobes, ribbons, cones, and cylinders. Most ctenophores are transparent but some are spotted with bright pigment. The body consists of two hemispheres. The mouth at the top of the globe forms the oral pole and the opposite (aboral) pole bears an anal pore. The body is further divided into equal longitudinal sections by eight ciliated bands which run from pole to pole. The bands, called comb rows or ctenes, give the phylum its name. Each row consists of a series of hairlike projections capable of rhythmic movement which enables ctenophores to swim (Buchsbaum 1938). Many ctenophores are bioluminescent along their ctenes. All ctenophores are hermaphroditic. The eggs and sperm are usually shed externally through the mouth and fertilization takes place in seawater and a free-swimming, cydippid larva develops. Eventually, the spherical larva is transformed into one of the several types of adult structures.

Two tentacles extend from the sides of the aboral hemisphere. Each is long, branched, and contractile. The epidermis of the tentacles possesses adhesive cells (colloblasts). An adhesive mucoid material is liberated when the cell comes into contact with prey. Ctenophores are carnivorous, feeding on other planktonic animals. They "fish" by using their branched tentacles to form a net. Prey are caught on the adhesive colloblasts and hauled in by retracting the tentacles as the body is rotated to bring the mouth in position to receive the food. The lobate ctenophores *Mnemiopsis* and *Bathocyroe,* which were observed within a few meters of the seabed at the shipwreck site, appeared to be using short tentacles near the mouth and the mucus-covered oral surfaces of the lobes to capture prey; Barnes (1987) noted that this technique was particularly effective for capturing small crustaceans.

Members of the Order Cestida become ribbon-shaped during their development stage, as the animals greatly elongate in a polar direction. *Cestus*, commonly called Venus' girdle, reaches lengths of over 1 m and swims by muscular undulations of its ribbon-like body, as well as by the beating of its combs. Small animals and other food particles, which are captured by adhesive tentacles running the full length of the body, are carried along a canal to a mouth groove at the mid-point of the ribbon. A creature resembling *Cestus* was observed and videotaped during a dive on the shipwreck in August 1990. Other more spherical, small, and brightly colored forms were occasionally observed, possibly *Aulococtena* in the family Bathyctenidae (Harbison and Madin 1982).

Phylum Nematoda

This phylum, also known as Nemata, consists of vermiform (worm-like) animals with a long cylindrical shape and circular cross-section, hence the common name roundworms. Nematodes are one of the most numerous and widespread groups of multicellular animals. Free-living nematodes, such as those found in deep-sea sediments surrounding the shipwreck, were typically small, benthic worms that lived in interstitial spaces between particles of marine sediments and algal mats. The size and form of nematodes reflect adaptations for living in interstitial spaces. Most have slender, elongated bodies that gradually taper at both ends, and are less than 2.5 mm in length. They generally lack color, having a collagen cuticle that is transparent, white, or yellow. The body is not segmented and lacks a distinct head. The mouth occupies the center of the anterior tip and is encircled by six lobes or lips which bear sensory papillae used for selecting food items within the sediment. A caudal gland (spinneret) that resembles a tube-like tail, is common in marine species and is used as an adhesive structure (Hyman 1951). Marine nematodes, with rare exceptions, are limited to the class Adenophorea.

Most nematodes move by undulatory waves of muscular contraction passing along the longitudinal muscles of the body wall creating a whip-like motion. The hydrostatic skeleton of internal fluids and the elasticity of the cuticle work in opposition to the bending of the body produced by muscle contraction. This action works best interstitially where the undulatory movements are applied against sediment particles. Many free-living nematodes are carnivorous, feeding on small benthic animals, including other roundworms. Teeth and jaw-like processes are typical of carnivorous nematodes. Other marine species feed on diatoms, algae, and fungi. There are also many deposit-feeding marine species, which ingest sediment particles, including dead organic matter and associated bacteria. Studies by Tietjen (1971) on the Atlantic continental slope off North Carolina in water depths between 1,000 and 2,500 m revealed a meiobenthic fauna where only nematodes and foraminiferans were present in large numbers. He found that 24 species occurred in the depth range of the SS *Central America* (2,000 to 2,500 m). These species have been arranged in taxonomic context with the assistance of Dr. W. Duane Hope, National Museum of Natural History, Smithsonian Institution (Table 13).

TABLE 13

Common species of nematodes found in sediments off the North Carolina coast at depths of 2,000 to 2,500 m.

PHYLUM NEMATODA
Class Adenophorea

Order Enoplida
- Family Oxystominidae
  - *Halalaimus filum* Gerlach 1962
  - *Halalaimus meyersi* Wieser & Hopper 1967
  - *Litinium bananum* Gerlach 1956
  - *Porocoma* sp. Cobb 1920

Order Araeolaimida
- Family Cylindrolaimidae
  - *Cylindrolaimus* sp. De Man 1880
- Family Diplopeltidae
  - *Diplopeltis incisus* (Southern 1914)
- Family Leptolaimidae
  - *Leptolaimus* sp. De Man 1876

Order Desmodorida
- Family Ceramonematidae
  - *Pselionema annulatum* (Filipjev 1922)
- Family Desmodoridae
  - *Acanthopharynx* sp. Marion 1870

Order Chromadorida
- Family Choanolaimidae
  - *Halichoanolaimus* sp. De Man 1886
- Family Cyatholaimidae
  - *Longicyatholaimus filicaudatus* Stekoven 1950
- Family Comesomatidae
  - *Comesoma* sp. Bastion 1865
  - *Sabatieria americana* Timm 1952
  - *Sabatieria triplex* Wieser 1954

Order Desmoscolecida
- Family Desmoscolecidae
  - *Desmoscolex americanus* Chitwood 1936
  - *Desmoscolex scanicus* Allgen 1935

Order Monhysterida
- Family Monhysteridae
  - *Filipjevia meridionalis* Kreis 1932
  - *Monhystera microphthalma* De Man 1880
  - *Theristus longicaudatus* Filipjev 1922
- Family Linhomoeidae
  - *Metalinhomoeus effilatus* Stekhoven 1942
  - *Metalinhomoeus retrosetosus* Wieser 1956
  - *Paralinhomoeus* sp. De Man 1907
- Family Sphaerolaimidae
  - *Sphaerolaimus* sp. Bastion 1856
- Family Siphonolaimidae
  - *Disconema minuta* Vitello 1969

Data Sources: Gerlach and Riemann (1973, 1974), Hyman (1951), Lorenzen (1981), Maggenti (1982), Platt and Warwick (1988), and Tietjen (1971).

In the deep range of the shipwreck, the numbers of individuals per 10 cm^2 of sediment ooze ranged from 32 to 56, about 10% of the population numbers Tietjen found on the continental shelf (50 to 500 m).

Most nematodes are dioecious and males are often smaller than females. The posterior of the male is curled like a hook. In copulation, the curved posterior of the male is usually coiled around the body of the female in the region of her genital pores (Barnes 1987). Marine species rarely produce more than 50 eggs which are deposited in clusters. The hatched young have almost all the adult structures and growth is accomplished by molts of the cuticle. Molting does not occur after the worm becomes an adult but the cuticle continues to grow (Maggenti 1982).

Phylum Sipuncula

Sipunculans (peanut worms) are a small group of drab-colored, non-segmented, marine worms that are generally less than 10 cm in length. All are bottom dwellers and rather sedentary in habit. Some live in sand and mud as active burrowers, dwelling in mucus-lined excavations while others live in coral crevices, empty mollusc shells, annelid tubes, or other types of protective retreats. The body is cylindrical and divided into an anterior narrowed section, called the introvert, and a larger posterior trunk. The introvert represents the head and contains a mouth which is surrounded by a group of ciliated tentacles. The entire introvert can be retracted into the trunk. Sipunculans are mostly non-selective deposit feeders. Sensory cells (chemoreceptors) located on the introvert are used to probe the environment. After the introvert collects material, it then invaginates and the food is ingested. Elevated coelomic fluid pressure through contraction of the body wall brings about the protrusion of the introvert (Barnes 1987). At the shipwreck, a sipunculan worm (*Golfingia margaritacea*) was recovered from an empty quill-worm tube (*Hyalinoecia artifex*) on the sediment ooze. The body was grayish-white in color and only a few centimeters in length. The tentacles were short and lobed. This species is bipolar in distribution and may be connected along the continental slope (Stephen and Edmonds 1972). Sipunculans are mostly dioecious. Ripe eggs and sperm leave the body by way of an excretory tube. Fertilization is external, with the egg developing directly into a sedentary individual or a free-swimming trochophore larva which normally settles to the bottom within a few days.

Phylum Pogonophora

Pogonophorans (beard worms) are a small group of primarily deep-sea, tube-dwelling worms. About 80% of the known species live below 200 m (Sumich 1992). They are distinguished by a thick, beard-like tuft of long tentacles that protrude from the top of their tube. They often live in a secreted chitinous tube that is usually vertical within sediment ooze. There are a few species that construct tubes in decaying wood or other debris (Barnes 1987). The body is divided into four regions: 1) anterior tentacular region which bears up to 200 tentacles, 2) frenular region which consists of a short anterior body, 3) long gonadal region bearing external papillae, and 4) terminal septate region. Most pogonophorans of the continental slope live partly buried in soft sediment (Southward 1971).

One family, Sclerolinidae, contains species that differ from other pogonophorans by the absence of several typical elements, including no clear division between the frenular and gonadal regions, lack of diversity in the type of papillae, and other morphological features (Webb 1964). Southward (1972) noted that most species in this monogeneric family live in pieces of rotting wood, natural-fiber rope, and other hard substrata on the ocean floor rather than in the soft mud occupied by other species. Thin, amber-colored tube-like structures were observed in decaying timber recovered from the SS *Central America* shipwreck in September 1991. In many cases the thin tubes passed through wood over a centimeter thick. Microscopic examination revealed a trunk structure similar to that described for *Sclerolinum*.

Pogonophorans are noteworthy in that they lack a mouth or internal digestive tract. The results of a variety of experiments suggest that these worms absorb some nutrients (e.g., amino acid, glucose, and fatty acids) through pinnules and microvilli of the tentacles without the aid of digestive enzymes (Cutler 1982). Studies of large pogonophorans from the Galapagos rift (Cavanaugh et al. 1981), show that trophosome tissue in the trunk of these worms is charged with symbiotic bacteria which fix carbon chemosynthetically and part of the organic products are absorbed by the hosts. Trophosomal tissue has also been found in small pogonophorans from the North Atlantic Ocean (Southward et al. 1981).

Most pogonophorans are dioecious with two cylindrical gonads located on sides of the trunk coelom. Sperm transfer, fertilization, and egg deposition have not been documented; spermatophores are thought to be released through the tentacular end of the tube and then carried to nearby females by water currents. Eggs are brooded within the tube.

Phylum Bryozoa

Bryozoans are very small sessile epifaunal organisms that form colonies large enough to be visible with the unaided eye. Also known as Ectoprocta, they are commonly called moss animals or sea mats because the colonies appear as branches or sheets of calcareous or chitinous "boxes" that form the living space for the individual organisms. The colony enlarges as the result of budding but begins with a free-swimming larva that lands on suitable hard surfaces. Bryozoans are the most prominent member of a group of phyla which possess a food-catching lophophore. This organ is a circular or horseshoe-shaped fold of the body wall that encircles the mouth and bears numerous ciliated tentacles. Cilia on the tentacles drive a current of water through the lophophore and plankton or organic debris is collected in the process. The individuals composing the colonies, known as zooids, are usually about 0.5 mm in length and are encased in a protective covering (zoecium) that contains an orifice for the protrusion of the lophophore. The shape of the zoecium can be box-like, oval, or tubular. An operculum over the opening is present in many bryozoans which seals the orifice when the lophophore is withdrawn. The lophophore bears 8 to 30 tentacles. When the tentacles are protruded they fan out to form a funnel to the mouth. Lateral ciliated tracts on the tentacles create a current that sweeps downward into the funnel. Tentacle flicking is also used to bat a particle down the funnel. Some bryozoans rotate the lophophore in a scanning behavior in search of food particles, while others merge the tentacles to form a cage around zooplankton prey (Winston 1978).

Most marine bryozoans are in the class Gymnolaemata. In this class, the zoecium consists of a protein-chitin cuticle which is sometimes underlain by a layer of calcium carbonate, forming a heavy, rigid exoskeleton. Members of this class live throughout the ocean, including the deep sea and were observed and collected at the shipwreck site. Most gymnolaemate colonies have polymorphic zooids; most are structured for feeding (autozooids) while others are modified for other functions (heterozooids) such as stolons (kenozooids), attachment discs, or root-like structures. Defensive heterozooids, called avicularia, are capable of whipping and pecking motions which protect the colony from small organisms, such as settling larvae of other animals. Another defensive structure is a vibraculum, which is a modification of the operculum to form a long bristle (seta) that can be used to sweep away debris and settling larvae.

Bryozoan colonies are attached to hard substrate in one of two ways: by a stalk (stolon) or by direct fusion of zooids. The vast majority of marine bryozoans are not stoloniferous but many form branching colonies that look like seaweed while others form encrusting colonies in which the zooids are organized as a sheet attached to hard surfaces. The *Sargassum* mats scattered over the ocean surface at the shipwreck site had abundant epiphytic colonies of the bryozoan *Membranipora.*

Although the zooids are microscopic, the colonies are macroscopic in size. The branching colonies recovered from a leather-bound trunk at the shipwreck site were up to 5 cm long. They were reddish-brown and scaly (similar in appearance to *Schizoporella*). Bryozoan colonies were also observed on the ironworks and some of the pottery at the shipwreck site. One partial specimen was found on a quillworm tube (*Hyalinoecia artifex*) by Dr. Henry M. Reiswig, Redpath Museum, McGill University, while removing a small demosponge (*Hymedesmia*). The bryozoan specimen was later identified as *Crassimarginatella* sp. by Dr. Judith E. Winston, Virginia Museum of Natural History. From the few zooids that were still intact, it was not possible to name the species. On comparing the specimen with the collections at the Smithsonian Institution and conferring with Dr. Alan Cheetham there, Dr. Winston concluded that the bryozoan collected on the site was most likely an undescribed species.

On the continental slope, rocky outcrops bear assemblages of bryozoans together with brachiopods, corals, and sponges. The maximum number of species per dredge sample decreases from 15 at 1,000 m to 5 below 2,000 m. Beyond the slope, the absence of hard substrate restricts the occurrence of sessile epifauna, including bryozoan colonies. Deep-sea bryozoans are commonly of the stoloniferous or encrusting type. Stomach contents from deep-sea bryozoans preserved shortly after capture include detritus but no recognizable organisms, suggesting that the zooids filter detritus in suspension over the bottom (Ryland 1970). Two principal predators of bryozoans, aside from nonselective scrapers like sea urchins, are pycnogonids (sea spiders) and nudibranchs.

Most marine bryozoans are hermaphroditic and most brood their eggs in an external chamber (ovicell). The larvae of brooding species are nonfeeding and have a very brief larval existence prior to settling. Larvae of nonbrooding bryozoans do feed and may have a larval life of several months. During settling, the larva is fastened to the substrate by secretions. The first zooid to develop is called the ancestrula. By budding, it gives rise to other zooids which, in turn, bud off new individuals. Thus, by asexual, reproduction the colony gradually increases in size. The lophophore and gut of a zooid degenerates after a few weeks and is often stored in the coelom as a dark ball (brown body). New, soft-body parts are regenerated within the same coelomic chamber.

Phylum Brachiopoda

Brachiopods, known as lamp shells, are similar to bryozoans in that they also bear a food-gathering lophophore. This organ is a horseshoe-shaped crown of tentacles surrounding the mouth. Brachiopods superficially resemble bivalve molluscs in possessing a calcareous shell of two valves and a mantle. However, the valves of a brachiopod are bilaterally symmetrical and each is usually convex. The ventral valve is typically larger than the dorsal one. The valves may be ornamented with concentric growth lines, ridges, flutes, and spines. Most shells are dull yellow-gray but some species have orange or red shells. The two valves articulate along a posterior hinge line. The nature of the articulation is the basis for dividing the phylum into two classes: Inarticulata and Articulata. Inarticulate brachiopods are held together only by muscles and tissue, whereas articulate brachiopods have a pair of hinge teeth on the ventral valve that fit into opposing sockets on the dorsal valve (Foster 1982). Small (<1 cm), dark reddish-brown colored, inarticulate brachiopods, possibly *Pelagodiscus* or *Discina,* were collected from the shipwreck. They were found attached to hard substrates, particularly pieces of iron and gold coins. They appeared limpet-like in their form of attachment. The dorsal valve was strongly concave and the ventral valve was nearly flat. The mantle edges bore relatively long setae.

All brachiopods are marine and occur from the intertidal zone to the deep sea. Most species live attached to rock or other firm surfaces but some live in vertical burrows in sand or mud bottoms. When feeding, water enters and leaves the valve gape through distinct inhalant and exhalant apertures and chambers created by the lophophore. The water is driven over the lophophore by cilia and food particles are screened out and transported down a groove to the mouth. Rejected particles are carried away by the outward flowing current.

Most brachiopods are dioecious. Eggs and sperm are generally shed into seawater where fertilization occurs.

The embryo eventually develops into a free-swimming and feeding larva. Inarticulate larvae, such as in *Pelagodiscus,* resemble minute brachiopods in that a shell is present (Foster 1982). As additional shell material is laid down, the larva becomes heavier and sinks to the bottom.

Phylum Hemichordata

Hemichordates are worm-like marine animals that have close phylogenetic relationships to both the echinoderms and the chordates (Barnes 1987). The phylum is composed of two classes: Enteropneusta (acorn worms) and Pterobranchia. Acorn worms, the most common and best known group, were likely responsible for many of the curvilinear mounds, grooves, and furrows which were observed in the soft sediments surrounding the shipwreck (Fig. 59). Enteropneusts are relatively large benthic animals, most ranging from 10 to 50 cm in length. The cylindrical, rather flabby body consists of a ciliated proboscis, a collar, and a long trunk that tapers to a small tail. A deep-sea form, most likely *Balanoglossus,* was photographed in the debris field to the stern of the shipwreck in the vicinity of several passenger trunks. The proboscis was short and conical, yielding the acorn shape from which the common name was derived. The mouth was located at the base of the proboscis where it was overlapped by the collar (Benito 1982).

All enteropneusts are dioecious. Masses of eggs embedded in mucus are shed from the burrow and are fertilized externally in the seawater or on the sediment surface by sperm emitted from nearby males. Release of the eggs probably stimulates males to release sperm. The mucus masses are often broken up by currents and the eggs dispersed. Early development can result in either a planktonic tornaria larva or more directly to a young worm.

Acorn worms have limited movement capability and are sluggish animals. Many burrowing species construct mucus-lined excavations in mud and sand. Burrowing or movement within the burrow is accomplished primarily by the proboscis, which is lengthened and then anchored by wave-like (peristaltic) contractions. This slow action was clearly visible in transmissions from the ocean floor. Most burrowing enteropneusts consume the sediment ooze through which they burrow, digesting organic matter and rejecting mineral particles. The large quantity of sediment ingested was indicated by the numerous curvilinear mounds on the seabed adjacent to the shipwreck.

In the deep sea, detritus and meiofaunal organisms are concentrated just below the surface of the sediment. Subsamples taken at different levels down a core of sediment from the South Atlantic Ocean showed that conditions for meiobenthic life were only favorable in the uppermost 5 cm of sediment and that nearly 60% of these minute animals inhabit the top 1 cm (Dinet 1973). Large worms that inhabit these areas may move over the bottom rather than in deep burrows (Heezen and Hollister 1971, Marshall 1979). This seemed to be the case for the deep-sea enteropneusts photographed at the shipwreck site which occupied shallow grooves.

PHYLUM CHORDATA: Subphylum Urochordata

Benthic ascidians, or tunicates, (class Ascidiacea) are primitive chordates which do not have true backbones but during their free-swimming larval stage they do have a notochord, a dorsal-tubular nerve cord, and pharyngeal gill slits. These three characteristics are typical of all animals in the phylum Chordata at some stage in their life but adult tunicates lose these features once they take up a sessile existence. Tunicates (so named because the outer body layer is a tough, often translucent "tunic" made of cellulose-like material, tunicin), often contract their body wall when disturbed and expel jets of water, hence another common name, "sea squirts."

The majority of ascidians are found in shallow waters; however, over 100 species have been taken from depths greater than 2,000 m (Monniot and Monniot 1975). In contrast to the shallow-water tunicates which live attached to rigid surfaces, most deep-sea species inhabit soft bottoms. Many are small, spherical species anchored by fibrils but some are large, stalked forms. Tunicates were rather inconspicuous members of the benthic community on the shipwreck. A few abyssal tunicates were observed on lumps of coal at Site H. They were connected to solid substrate by long, slender stalks, and had small tunics. Images in the photographs from Site H resembled deep-sea forms such as *Culeolus* or *Doltenia.*

The bodies of solitary ascidians range from spherical to cylindrical in shape with one end attached to the substrate, and the opposite end containing two openings (buccal and atrial siphons). The buccal siphon serves as an incurrent passage for water which passes into a chamber within a pharyngeal basket. The basket is housed within a cavity (atrium) and is perforated with small slits (stigmata), permitting water to pass from the interior of the basket to the atrium and finally out the atrial siphon. Tunicates filter plankton and organic particles from the water current that is produced by the beating of cilia on the edges of the stigmata. Food particles are wrapped in mucus strands before passage across the pharynx. Large quantities of water are strained for food by these animals, for example, a tunicate only a few centimeters long can pump water at a rate of 7.2 l/hr (Barnes 1987).

Most tunicates are hermaphroditic. In solitary species, such as those observed at the shipwreck site, the eggs and sperm are shed from the atrial siphon and fertilization takes place in the seawater. A tadpole-like larva develops which swims with a long, posterior tail. At this stage, the larva has a notochord and a neural tube, as well as the slits in the pharynx. At the end of the free-swimming stage (a few days), the larva settles to the bottom and attaches by anterior papillae. A radical metamorphosis then ensues, in which the tail, notochord, and neural tube are resorbed and the entire body is rotated so that the mouth is at the opposite end from the attachment.

PHYLUM CHORDATA: Subphylum Vertebrata

Cartilaginous fishes (class Chondrichthyes) and bony fishes (class Osteichthyes) were among the largest animals living on or near the deep seafloor at the shipwreck sites (Fig. 116). Most of them ranged from 20 to 100 cm in length. The major exception was a 6-m Greenland shark (*Somniosus microcephalus*). The most common fishes were eels, macrourids, halosaurs, ophidiids, morids, eelpouts, and deep-sea sculpins. All but the latter two groups possessed swim bladders and swam with ease within a few meters of the bottom (benthopelagic fishes). Those lacking swim bladders usually appeared in contact with the bottom (benthic fishes).

Class Chondrichthyes

This class of marine fishes includes sharks, skates, and chimaeras, all of which were observed within a few meters of the floor of the Atlantic Ocean in the vicinity of the SS *Central America* shipwreck. These vertebrates lack true bone but have cartilaginous skeletons. They all have well-developed jaws, bony teeth, skin composed of tooth-like (placoid) scales, paired limbs, and lack a swim bladder. Sharks have streamlined bodies and are characterized by 5 to 7 pairs of gill slits, nostrils that do not open to the mouth, and dorsal fins, often with rigid spines. Skates have large, wing-like pectoral fins that are joined to the front of the head to form a platform snout. Chimaeras (ghost sharks) are rather awkwardly shaped fish, having a second dorsal fin that is much longer than the first but lacking the extended beaks of sharks. Their bodies are laterally compressed and taper toward the rear to a slender, rodent-like tail; thus they are commonly referred to as ratfishes. In sharks, the skin is filled with small, overlapping placoid scales, giving it a sandpaper feel. These scales provide a lightweight, protective coat that increases hydrodynamic efficiency. In skates, the scales are typically found only as a few rows of large denticles on the back which are sometimes modified into spines, whereas in chimaeras, the scales are absent except as teeth.

In sharks, forward propulsion is provided by lateral undulations of the tail and body. Lift is effected by the slanted surfaces of the pectoral and pelvic fins. Steering and stability are maintained by their characteristic heterocercal tail, designed with the upper lobe of the caudal fin much larger and more flared than the lower lobe. Skates and rays are flattened dorsoventrally and mostly move about by flapping or undulating their extremely large pectoral fins. The long, narrow tails of chimaeras are not as effective as their large pectoral fins for locomotion.

Most chondrichthyan fishes are specialized predators as reflected by their tooth form and dentition. Sharks that prey on large fishes and marine mammals have triangular, blade-like teeth which can grab their prey and tear or bite off sizable pieces while those that swallow their prey whole (e.g., fishes or squids) have long, thin, pointed teeth for holding the prey so it can be swallowed. Skates, rays, and chimaeras tend to have flattened teeth plates for crushing hard-shelled molluscs and crustaceans which dwell on the ocean floor. Despite the variety, however, all chondrichthyan teeth are simply modified placoid scales and like the dermal scales, they are continually being shed and replaced.

Sharks are extremely efficient at finding food and employ several senses, each most effective within a set distance from a potential food item. The following senses are progressively used as the shark approaches food: 1) hearing–thousands of meters, 2) olfaction–500 m, 3) pressure pulse on lateral line–100 m, 4) salinity pulse on neuromasts–50 m, 5) vision–15 m, 6) temperature pulse on ampullae of Lorenzini–5 cm, 7) taste–contact (Pope 1973).

For example, within a matter of hours after fish carcasses and fish meal were deployed on the ocean floor at the shipwreck, two Greenland sharks (*Somniosus microcephalus*) had approached the bait (Table 14). The inner tissue of the olfactory pit of sharks has a great number of sensitive lamellae which are continually bathed by seawater from the outside. Sharks typically have 2,000 m^2 of intricately folded smelling surface which accounts for their keen sense of smell (MacGinitie and MacGinitie 1968).

In addition to the deep-water observations, two other species of sharks were observed at the ocean's surface above the shipwreck site: 1) oceanic whitetip shark (*Carabarinus longimanus*) and 2) whale shark (*Rhincodon typus*) (Fig. 117). Oceanic whitetip sharks are entirely pelagic, occurring far out at sea in tropical and subtropical parts of the western Atlantic Ocean. These sharks were seen virtually every day from the R/V *Arctic Discoverer* and via *Nemo*'s cameras as the submersible moved through the sunlit portion of the sea. These sharks had a short, broadly rounded snout, and rounded pectoral and first dorsal fins but the dorsal fin was large and high. The 2- to 3-m long body was light gray to olive drab colored on the dorsal surface and yellowish-brown beneath. Whitetips appeared to be particularly fond of galley scraps. One night in July 1989, under floodlights, seven of these sharks were thus attracted to the ship. In July 1990, a whale shark lazily circled the ship for three hours. At 5.2 m, it was probably a juvenile since adults reach about 18 m in length. Whale sharks roam the warm seas feeding primarily on plankton which they collect on a sieve-like mesh over their gills. Unlike most sharks, their snout does not project beyond the mouth. This shark's gray back was dotted with "snowflake-like" white spots and decorated with transverse, yellowish-white stripes. The shark lazily circled the ship then drifted off. Although well known because of their tremendous size, whale sharks are rare (Clark 1969).

As a general rule, female chondrichthyans grow considerably larger than their male counterparts. Male sharks, skates, and chimaeras can also be distinguished from females by their twin, external, copulatory organs (claspers) which are located on the inner edge of the pelvic fins. These claspers point to the rear but during copulation they turn forward so they can enter the female's vent to release sperm internally. The claspers of each species are distinct, thus, they only match up with the vents of females of that species. The claspers of a male Greenland shark (*Somniosus microcephalus*) could readily be seen on video images as it cruised over the site in 1990, whereas, none were visible on a skate (*Raja jenseni*) photographed at Site H in 1987, indicating the latter was probably a female.

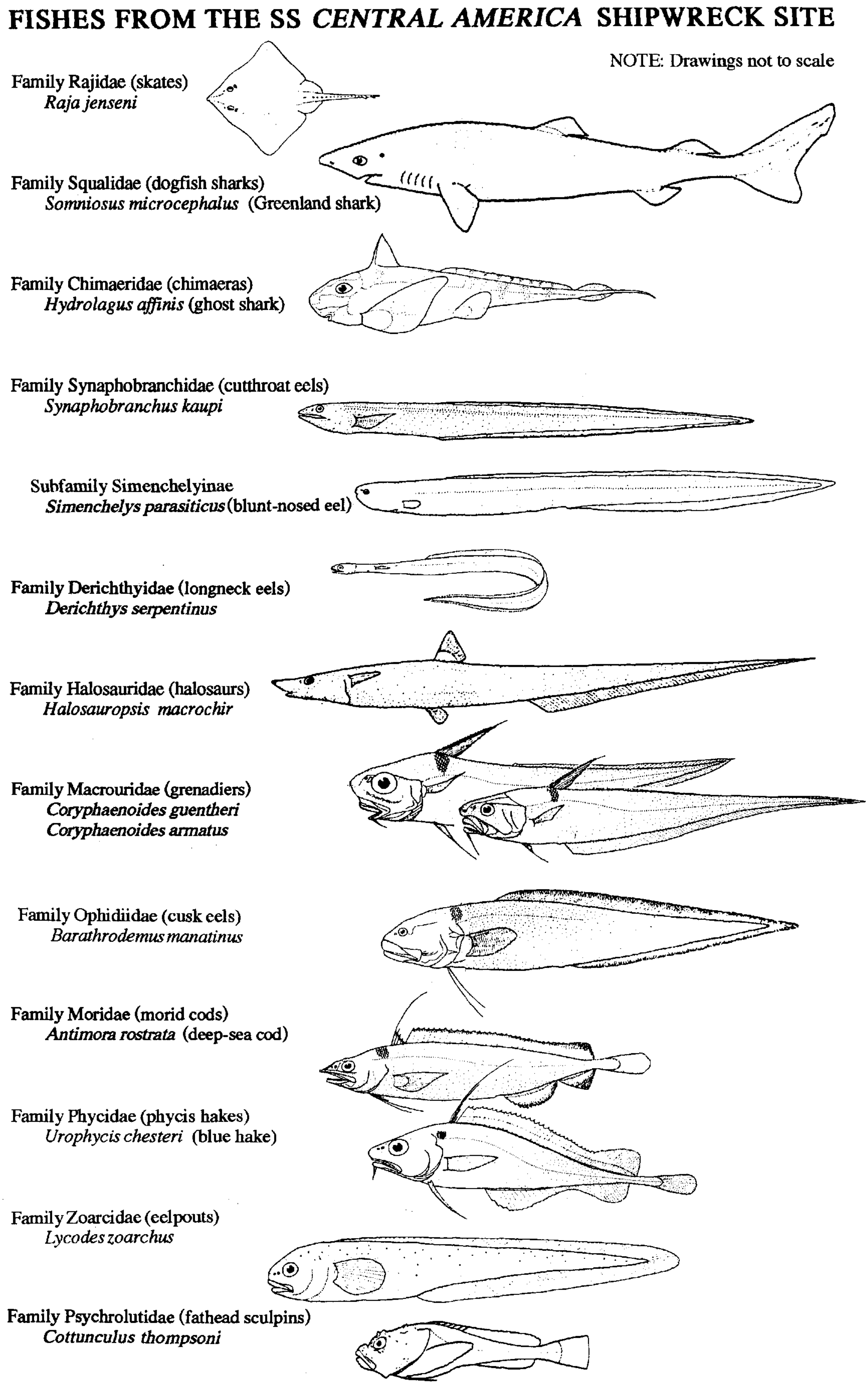


FIGURE 116. Diagram of the 14 most common fish species observed on the shipwreck sites.

TABLE 14

1990 bait experiment – summary timeline
SS Central America *shipwreck site.*

Date/Time	Cumulative Time	Event
1990		
31 Aug/14:11	00:00	Select experiment station
31 Aug/14:47	00:36	Complete building of bait pile (50 kg)
31 Aug/14:49	00:38	BN eels (3) arrive at station
31 Aug/18:27	04:16	Grenadier arrives at station
31 Aug/19:05	04:54	Set bait trays (2 cornmeal, 2 fish meal)
31 Aug/19:26	05:15	Set bait traps (2)
31 Aug/20:06	05:55	CT eel arrives at station
31 Aug/20:28	06:17	Deep-sea cod arrives at station
31 Aug/21:16	07:05	Greenland shark (6 m) arrives at station
31 Aug/21:46	07:35	Greenland shark (2.5 m) arrives at station
1 Sep/00:08	09:57	No fish present at station
1 Sep/00:26	10:15	BN eels (2) and grenadier return to station
1 Sep/00:33	10:22	Greenland shark (6 m) returns to station
2 Sep/04:42	38:31	Eelpouts (3) and BN eels (2) at station
2 Sep/04:48	38:37	Serpent eel arrives at station
2 Sep/05:59	39:48	Recover trap with BN eel (later escapes)
2 Sep/06:54	40:43	BN eels (4) and eelpouts (2) at station
2 Sep/09:07	42:56	Feeding frenzy begins (~20 BN eels)
2 Sep/09:18	43:07	Feeding frenzy reaches peak (~50 BN eels)
2 Sep/22:52	56:41	Greenland sharks (2) above station
4 Sep/00:05	81:54	No BN eels at station; fish meal trays gone; eelpouts (3) and grenadier at station
4 Sep/04:02	85:51	Eelpouts (3) and grenadier at station
4 Sep/12:41	94:30	Eelpouts (3) and BN eels (2) at station
11 Sep/11:08	260:57	Eelpouts (12) and CT eel at station
12 Sep/12:18	286:07	Recover trap with eelpout (retained)
12 Sep/12:56	286:45	No BN eels at station
21 Sep/03:01	492:50	Chimaera over station
30 Sep/18:35	724:24	Eelpouts (~10) at station; only bones/skin remain
5 Oct/05:58	821:47	Eelpouts (~10) at station; only bones remain
1991		
17 Jun/19:26	6965:15	Only bones and slime mold at station; large sea cucumbers; brotulid strikes at crab feeding on a polychaete worm

Note: BN eel = blunt-nosed eel (*Simenchelys parasiticus*)
Brotulid = (*Barathrodemus manatinus*)
Chimaera = (*Hydrolagus affinis*)
CT eel = cutthroat eel (*Synaphobranchus* sp.)
Deep-sea cod = (*Antimora rostrata*) and/or (*Urophycis chesteri*)
Eelpout = (*Lycodes zoarchus*)
Greenland shark = (*Somniosus microcephalus*)
Grenadier = (*Coryphaenoides* spp.)
Serpent eel = (*Derichthys serpentinus*)

Unlike the bony fishes, cartilaginous fishes produce a relatively small number of large, active young. Development of the young takes one of three different pathways: 1) oviparity, 2) ovoviviparity, or 3) viviparity. Oviparous forms lay large eggs enclosed in tough, leathery capsules that are attached to the substrate and left to hatch. Many of these cases have tendrils at the corners for attachment to seaweed and other bottom structures. Ovoviviparous forms retain rather thin-shelled eggs in the uterus of the female and continue to retain the young after hatching until they are fully developed. In some cases, the newly hatched sharks feed internally on other eggs and young (oophagy) until they are ready to be born. Viviparous forms have a placenta similar to that of mammals. The juveniles are born large enough to exist on their own without parental care.

Order Rajiformes. This order includes skates and rays as well as a few unusual groups such as sawfishes and guitarfishes. This group is separated from the sharks by four main features: 1) the five gill openings are located wholly on the underside of the body, 2) the pectoral fins are enlarged and connected to the sides of the head in front of the gill slits, 3) the eyeballs are connected to the upper edges of the eye socket rather than being unattached, as in sharks, and 4) skates and rays have no anal fins. Most skates and rays are sedentary, bottom-dwelling creatures that often rest partially buried in the bottom sediment. Skates do occasionally swim and at Site H one was photographed a meter or so above collapsed hull timbers. Many species feed entirely on benthic invertebrates, while a few prey on fish.

Skate (*Raja jenseni*). This fish was photographed in 1987, swimming over the wooden hull of a shipwreck at Site H, about 60 km east of the SS *Central America*. The body of this species was diamond-shaped (Fig. 118). The upper surface of the skate was light in color as compared with the dark timbers.

FIGURE 117. A whale shark (*Rhincodon typus*) gently circles the R/V *Arctic Discoverer*, 2,200 m above the shipwreck of the SS *Central America*. This harmless giant feeds on tiny planktonic creatures floating in the water. The blunt nose and "snow-flake" pattern are characteristic of this species. A white suckerfish (*Remorina albescens*) hitches a ride on the back of the shark. Typical of all remoras, it has a sucking disk on top of its head where it is attached to the dorsal surface of the shark, giving the remora an upside-down ride. Because the whale shark is a plankton feeder, few scraps result from its food and the remora most likely feeds on ectoparasites on the shark's body.

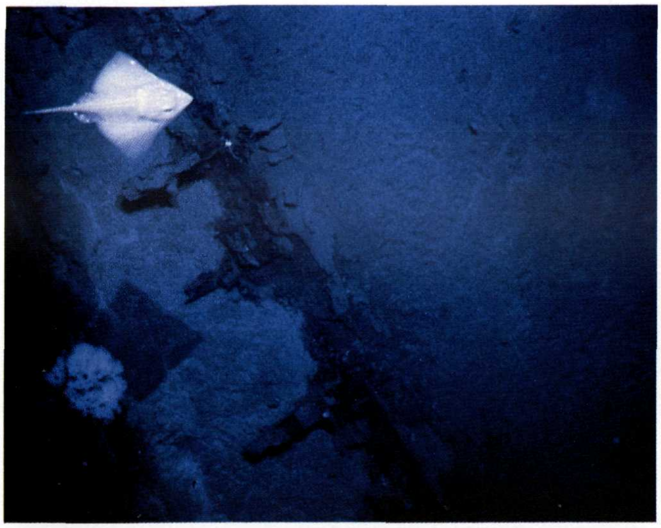


FIGURE 118. A female skate (*Raja jenseni*) cruises over the shipwreck at Site H. The hull timbers and hanging knees can be seen below the skate's head. A large glass sponge (*Caulocalyx* sp.) is visible on the interior timbers near the skate's shadow.

The lack of claspers at the trailing edges of the enlarged pectoral fins indicated that the individual was probably a female. Dr. C. Lavett Smith, Department of Ichthyology, American Museum of Natural History, provided the tentative identification of this species from the photograph. Typically, skates lay horny egg cases that are anchored to the bottom by long, coiled tendrils at each corner. Development is slow and the eggs may take up to several months to hatch. Little is known about the specific life history of this species. Brundage et al. (1967) photographed what is believed to be a male *R. jenseni* off Georges Banks at a depth of 2,500 m and Templeman (1965) captured a rare individual of this species off Newfoundland. Skates are more abundant than rays in deep, cold water. Skates glide smoothly forward by passing waves along the pectoral fins from front to rear. The caudal fin is greatly reduced resulting in a slender tail.

Order Squaliformes. Sharks of this order are known as dogfishes and are widely distributed. All have two dorsal fins and many have spines preceding one or both fins. Although the sleeper sharks (*Somniosus* spp.) may exceed 6 m in length, most squaliform sharks seldom exceed 2 m in length. A 6-m Greenland shark (*Somniosus microcephalus,* family Squalidae, subfamily Dalatiinae) was observed on the shipwreck site. However, the smallest known sharks (*Squaliolus laticaudus*), at less than 25 cm, are also in this order (Nelson 1984). Possibly the best known and most abundant shark worldwide is the spiny dogfish (*Squalus acanthias*) which is common in coastal temperate to subpolar waters. The "dog-fish weighing several pounds" that "jumped on the raft" and was secured by survivors of the SS *Central America* disaster (Conrad 1988) was likely this species. George W. Dawson, a passenger who was rescued by the brig *Mary* nine days after the sinking, commented in a *New-York Daily Tribune* interview of 6 October 1857, that the shark's: "skin and meat were so tough that they could hardly cut or eat it, and they satisfied themselves by masticating a small quantity of it" but by: "the next day was more tender, and it was soon eaten."

Greenland Shark (*Somniosus microcephalus*). One of the most startling observations of the expedition was in the late hours of 31 August and the early hours of 1 September 1990, when a 6-m-long Greenland shark cruised through a bait experiment station on the shipwreck site. The length was estimated by comparing the shark's image with an imprint of where *Nemo* had recently landed on the ocean floor (Fig. 119). At the station, 50 kg of grouper, red snapper, and mackerel carcasses, as well as trays of fish meal and grain, had been placed the day before to attract whatever scavengers and predators might inhabit the area (Figs. 120, 121). Just as *Nemo* was lifting off the bottom, the shark appeared and brushed against one of the camera booms. Later, this shark and a smaller individual of the same species (2.5 m) were seen from high above the wreck, slowly swimming toward the pile of carcasses. Approximately 50 blunt-nosed eels (*Simenchelys parasiticus*) and several other fish species were feeding at the station when the sharks approached. When *Nemo* returned to the station, the cameras revealed that no eels remained and two fish meal trays were missing (Table 14).

Video transmissions of the Greenland shark showed it to have a dark brown skin color and an eye that was distinctly white and luminous. The caudal fin was short and blunt, being only slightly asymmetrical by way of an enlarged upper lobe. The first dorsal fin was located characteristically midway between the pectoral and pelvic fins. Claspers indicated the shark was an adult male. Dr. Eugenie Clark, Department of Zoology, University of Maryland, provided a preliminary identification of the shark as *Somniosus microcephalus* from a description given to her via satellite telephone immediately after the sighting. She later confirmed the identification by viewing videotape of the encounter and concluded that at 2,200 m, these images represented the deepest direct observation of a shark anywhere in the world ocean. Dr. Clark also noted that the shark's claspers were somewhat smaller than anticipated and that bioluminescence is known to occur in the eye region of Greenland sharks.

The Greenland shark is a giant in the spiny dogfish family and is the largest Arctic fish. It has an elongated robust body which tapers rapidly toward the tail with a body depth-to-length ratio (d/l) of 0.26, which allows movement through water with minimal work (McMahon and Bonner 1983). The coloration of the body is a uniform dark gray or brown to blue-gray above and somewhat paler gray below. The skin is uniformly covered with fine tubercles. These sharks are large and bulky with a broadly rounded snout. They have relatively small fins for their size and the two dorsal fins are spineless. The first dorsal fin begins above a point midway between the pectoral and pelvic fins. The caudal fin is short and blunt, being only slightly asymmetrical with an enlarged upper lobe bearing an extension of the vertebral column. Their teeth are

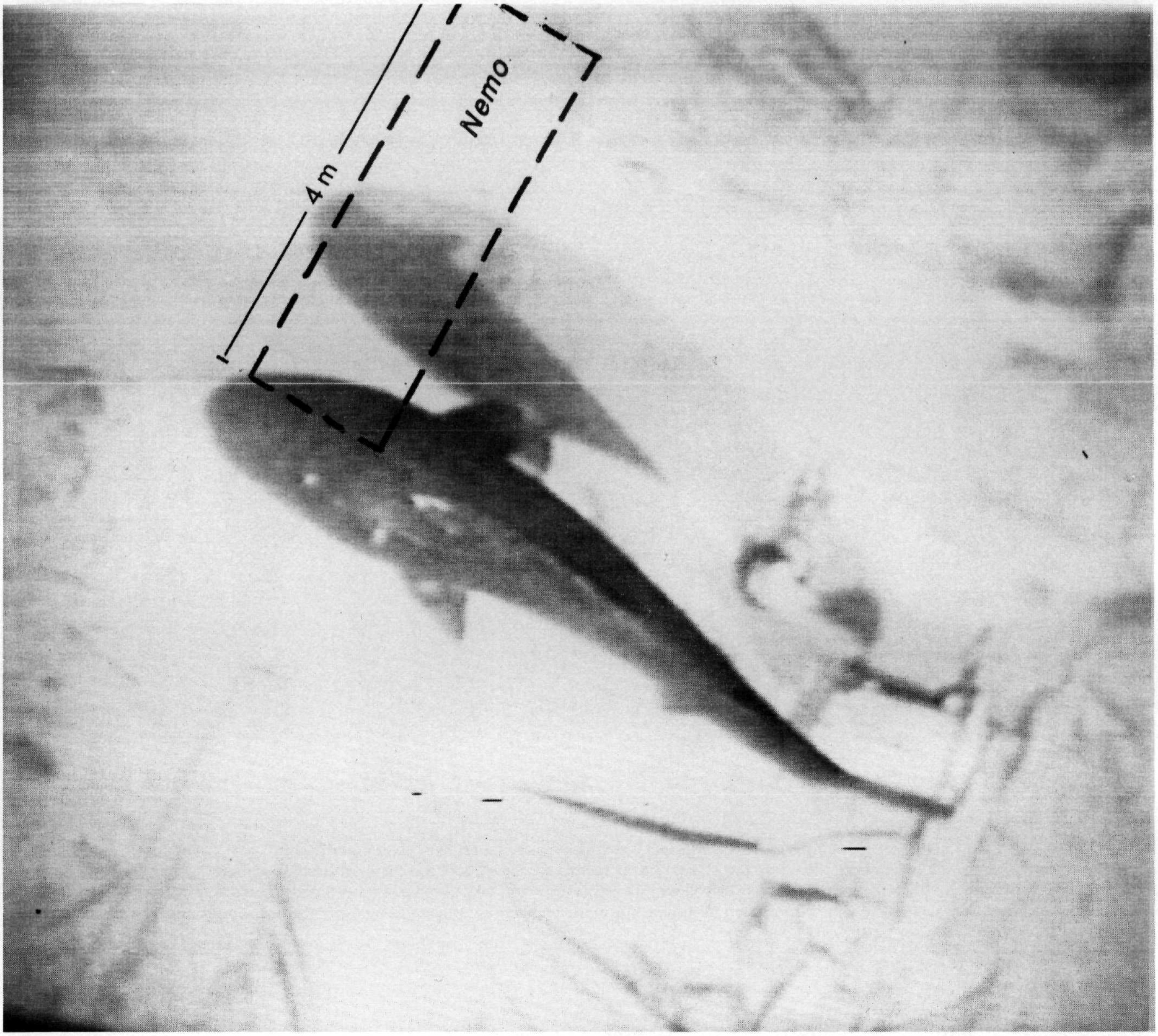


FIGURE 119. A Greenland shark (*Somniosus microcephalus*) cruises over the shipwreck of the SS *Central America* at a depth of 2,200 m. This 6-m-long male was photographed 1,000 km farther south and 1,000 m deeper than any previous record for this species. This is the deepest known photograph of a large shark in the world ocean. The length of this shark was determined by comparing its image with a 4-m-long impression of the submersible *Nemo*, made when it landed on the ocean floor. The Greenland shark either followed the bait as it was carried to the seabed by *Nemo* or it was attracted by the feeding activity of some 50 blunt-nosed eels (*Simenchelys parasiticus*) as they frantically devoured 50 kg of bait (fish carcasses) placed on the wreckage several hours earlier (see Fig. 120).

arranged in several rows, five dagger-like rows on the upper jaw and six broadly triangular and outward-directed rows on the lower. The eyes are not protected by a nictitating membrane. The largest recorded individual for this species was 7.3 m long and weighed 1,020 kg (Pope 1973).

The deepest record for *Somniosus microcephalus* reported by Robins and Ray (1986) was 1,200 m and the southern most sighting was Cape Cod, which is about 1,000 m shallower and 1,200 km farther north than the present observation (Table 15). A close relative, *Somniosus pacificus*, has been observed at a depth of 1,630 m from a submersible in the Pacific Ocean (Clark and Kristof 1990). Greenland sharks normally live in the Arctic waters of the Atlantic, rarely straying southward and they spend much of the time lying on or near the bottom, rising only to feed (Migdalski and Fichter 1976). They are omnivorous, feeding on any available prey, large or small. Mattox (1973) characterized the Greenland shark, as its scientific name indicates, as a lethargic, small-brained fish. They are reputed to be slow moving and sluggish, hence the common name "sleeper shark" used in the Pacific for *Somniosus pacificus* but they are probably no more sluggish than other bottom-living sharks. Pope (1973) noted an interesting paradox: while this shark is reputed to be slow, seal, reindeer, cod,

FIGURE 120. An abyssal grenadier fish (*Coryphaenoides guentheri*) swims over an experiment station at the shipwreck of the SS *Central America*. About 50 kg of fish carcasses have been placed on the shipwreck as bait to attract deep-ocean fishes and other animals. Several blunt-nosed eels (*Simenchelys parasiticus*) are feeding on carcasses. Three yellow pine posts (60 x 10 x 10 cm) have also been placed on the site to attract wood-boring bivalves. The collapsed timbers of the ship can be seen in the background. The yellow sphere (12.6 cm) in the left foreground was used as a scale and visual marker to help locate the station.

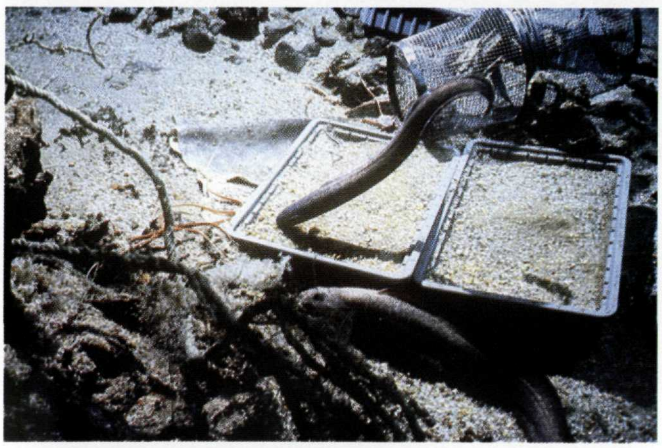


FIGURE 121. A blunt-nosed eel (*Simenchelys parasiticus*), at top, and an eelpout (*Lycodes zoarchus*), at bottom, feed from trays filled with fish meal at a bait experiment on the shipwreck. The eelpout was later captured in the trap (baited with beef) shown at the upper right. This specimen, the only fish recovered from the site, is now in the collection of the American Museum of Natural History, New York. Large brittle stars, seen at top center and left center, were also attracted by the bait.

halibut, salmon, herring, porpoise, seabirds, squid, and various crustaceans have been found in their gut. Wheeler (1975) indicated they were well known as scavengers around Arctic whaling stations and gorged themselves on floating whale carcasses. This voracious food habit may explain the disappearance of the fish meal trays and the eels at the bait experiment station (Table 14).

Tagging of Greenland sharks in the North Atlantic has shown that they grow slowly and live for many years (Ayling 1987). Goode and Bean (1895) noted that Greenland sharks descend to considerable depths and deposit numerous soft, globular eggs, devoid of protective covering, in the soft, deep-sea mud. A conflicting report by Wheeler (1975) indicates that these are live-bearing (viviparous) sharks, with litters of up to ten and the young are about 40 cm in length. Mattox (1973) points out that it was not until 1954 that live birth was proven for this shark and that much of its life history still remains unknown. Although large numbers of this species are caught annually, only one gravid female has been found (Ayling 1987).

TABLE 15

Large and deep-habitat sharks of the North Atlantic Ocean.

Phylum Chordata	Max. Length (m)	Max. Wt. (kg)	Deepest Range (m)
Class Chondrichthyes (cartilaginous fishes)			
Subclass Elasmobranchii (sharks and rays)			
Order Hexanchiformes (cow sharks)			
Family Hexanchidae (sixgill sharks)			
Hexanchus griseus (sixgill shark)	4.9	580	1,870
Order Squaliformes (dogfish sharks)			
Family Squalidae (spiny dogfish sharks)			
Somniosus microcephalus (Greenland shark)	7.3	1,020	2,200
Centroscymnus coelolepis (Portuguese shark)	1.1	–	2,700
Centroscyllium fabricii (black dogfish)	1.1	–	1,500
Dalatias licha (kitefin shark)	1.8	–	1,645
Order Pristiformes (sawfishes)			
Family Pristidae (sawfishes)			
Pristis pectinata (greater sawfish)	7.6	2,270	<1,000
Order Squatiniformes (angel sharks)			
Family Squatinidae (angel sharks)			
Squatina dumerili (Atlantic angel shark)	1.5	–	1,300
Order Orectolobiformes (carpet and nurse sharks)			
Family Rhincodontidae (whale sharks)			
Rhincodon typus (whale shark)	18.3	20,000	<1,000
Order Lamniformes (typical sharks)			
Family Alopiidae (thresher sharks)			
Alopias vulpinus (thresher shark)	6.1	450	<1,000
Alopias superciliosus (bigeye thresher)	5.5	–	<1,000
Family Cetorhinidae (basking sharks)			
Cetorhinus maximus (basking shark)	13.7	6,000	<1,000
Family Lamnidae (mackerel sharks)			
Carcharodon carcharias (white shark)	8.0	3,300	<1,000
Order Carcharhiniformes (dogfish sharks)			
Family Scyliorhinidae (cat sharks)			
Apristurus sp. (deep-water cat shark)	0.7	–	1,150
Family Triakidae (smooth dogfish sharks)			
Mustelus canis (smooth dogfish shark)	1.5	–	1,200
Family Sphyrnidae (hammerhead sharks)			
Sphyrna mokarran (great hammerhead shark)	6.1	–	<1,000

Note: Large sharks are here defined as those larger than 5 m in length and deep-habitat sharks are those who have been reported at depths greater than 1,000 m. Of the eight species larger than 5 m, the Greenland shark is the only deep diver (direct observation). The small Portuguese shark has been reported at greater depths but records for this shark are derived from commercial fishing operations where sharks may have been caught as the gear was in transit.

Data Sources: Bigelow and Schroeder (1953), Pope (1973), Wheeler (1975), Migdalski and Fichter (1976), Robins and Ray (1986), Clark and Kristof (1990), and present study (Greenland shark).

The Greenland shark was once an important fishery for Greenlanders. Because it lacks fight, Greenlanders could hook and land large individuals from kayaks. Typically, the sharks caught off West Greenland were about 4 m in length and one ton in weight (Mattox 1973). Robins and Ray (1986) reported annual catches as high as 32,000 for the fishery off Norway, Iceland, and Greenland. Formerly, meat from the Greenland shark was used to feed sled dogs but of more importance was the liver which rendered oil for lamps and later for medicinal purposes (as a source of vitamin A). The liver averages 15 to 25 kg, although the record is over 300 kg (Mattox 1973). The skin was also tanned and used to make fine leather for handbags and bookbinding. Catches of the Greenland shark species have greatly declined since 1963.

Order Chimaeriformes. There are some 25 species of chimaeras; most of them are in the family Chimaeridae. One species in this family, *Hydrolagus affinis*, was observed at the shipwreck site. Chimaeras are related to the elasmobranchs but have had a long, independent evolutionary history as reflected by their anatomy. These ratfishes have a long, slender tail and a body shape that is convergent with deep-sea bony fishes, such as the macrourids (or rattails). Chimaeras have crushing teeth for feeding on benthic invertebrates. For defense, they have spines in front of the dorsal fin with an associated venom gland. All chimaerids are oviparous, laying large eggs in a horny or leathery egg case that is deposited on the bottom. Like most sharks and skates, development is slow and the young do not hatch until six months to a year after the eggs are laid.

Chimaera (*Hydrolagus affinis*). This fish, sometimes called "ghost shark" was first observed as a shadow on the site in September 1989, as it swam between the video camera and the lights which were mounted higher up on *Nemo*. The fish entered the field of view from the upper right at a moderate speed, swam directly toward the vehicle, and collided with *Nemo*. Presumably the fish was either blind or blinded by the bright lights. It bounced off, gave a tight 180° turn as an apparent avoidance movement, and quickly exited the field of view to the right. From the shadow, the fish had rather large, triangular pectoral fins, which flapped as it swam, an elongated, tapering head, and an asymmetrical caudal fin with an upward projection. Dr. Eugenie Clark examined the videotape and concluded that the shadow was that of a chimaera. The deep-water rabbitfish, also called long-nosed chimaera (*Harriotta raleighana*), is known from the North Atlantic to depths as great as 2,600 m and may have cast the shadow. Wheeler (1975) pointed out that relatively few specimens of this species have ever been caught, and its biology is virtually unknown. However, in 1991, excellent images were obtained of the same or quite possibly another chimaera. This individual was reddish-brown in color and from a side view the snout did not appear as elongated nor the caudal fin as broad as the shadow image. Dr. Daniel M. Cohen, Natural History Museum of Los Angeles County and Dr. Richard H. Rosenblatt, Scripps Institution of Oceanography, viewed the 1991 videotape and concluded that the chimaera was the ghost shark *Hydrolagus affinis*.

Chimaerids are closely related to sharks but differ in that the five external gill slits of sharks are covered in chimaerids by an operculum, leaving a single outside gill opening on each side as in bony fish. Chimaerids have a smooth skin with no dermal denticles. Male chimaerids have the type of claspers that are present in sharks but they also have a second pair of flat, retractable claspers in front of the pelvic fin that are armed with hooks for gripping the female during mating. Chimaerids live mainly on the soft sediments of the deeper part of the continental shelf and slope.

Class Osteichthyes

This class includes all of the bony fishes, a large and diverse group. The modern bony fishes are placed in the superorder Teleostei and six orders within this group were observed on the shipwreck: Anguilliformes, Notacanthiformes, Gadiformes, Ophidiiformes, Perciformes, and Scorpaeniformes (Appendix A). The classification of fish genera used in this paper follows that of Eschmeyer (1990). Identification of the ten or more species of bony fishes observed on the site was undertaken by ichthyologists viewing videotape and still photographs of the shipwreck site: Dr. Eugenie Clark, University of Maryland; Dr. Daniel M. Cohen, Natural History Museum of Los Angeles County; Dr. Charles F. Cole, The Ohio State University; Dr. William N. Eschmeyer, California Academy of Sciences; Dr. Barbara Hecker, Columbia University; Dr. Tomio Iwamoto, California Academy of Sciences; Dr. Samuel B. McDowell, Rutgers University; Dr. Richard H. Rosenblatt, Scripps Institution of Oceanography; and Dr. C. Lavett Smith, American Museum of Natural History.

Owing to its diversity, the class is difficult to define precisely because there is no one feature which distinguishes it. Rather, there is a common structural pattern (e.g., presence of bone, fins, scales, and swim bladders), combined with the absence of features characterizing the cartilaginous (Chondrichthyes) and jawless (Agnatha) fishes. Bony fishes differ from cartilaginous fishes in having a completely ossified bony skeleton and a bony gill cover (operculum) that protects the cavity containing the gills, leaving only a single gill slit. The fins are membranous and strengthened by a series of spines or soft rays. The fins can be folded flat against the body. Unlike the placoid scales of the shark, bony fishes have overlapping (cycloid or ctenoid) scales. However, scales are completely lacking in some species. Swim bladders function primarily as hydrostatic organs by providing added buoyancy in most species. Some teleosts have lost the swim bladder as an adaptation to a benthic existence.

The general features of the body of a teleost fish are similar in many respects to those of a shark. One major difference is that the teleost caudal fin is usually a regular shape (homocercal) with the upper and lower halves symmetrical, whereas in sharks, the upper and lower lobes are asymmetrical (heterocercal). However, in some cases, particularly in the deep sea, the dorsal and anal fins are continuous with the caudal fin giving an eel-like body shape.

Bony fishes use three different swimming methods depending on their body design. Most use a side to side undulation. For example, the eels observed at the site moved slowly with many pronounced lateral undulations giving the body an S-shape when swimming, while grenadiers moved more rapidly with only a slight flexing of the body. Other fishes, like the deep-sea cods, swam by means of rhythmic beats of their pectoral fins, propelling themselves along in a series of pulses.

Teleost fishes have a wide range of tooth shapes and arrangements and feed on a correspondingly wide range of different foods. Most fishes observed at the site were bottom feeders and opportunistic scavengers. Others fed on encrusting animals such as sponges and tunicates, or preyed on crabs, worms, and molluscs from the seabed. A few may also have been partially piscivorous. Unlike shark teeth that are present only in the jaws, teleost teeth may occur on any of the bones of the mouth and pharynx (Nelson 1984).

Teleost fishes are dioecious. In the majority of deep-sea species, the males and females release their sperm and eggs separately into seawater during spawning to mingle and fertilize. In most species, the females produce very large numbers of small buoyant (pelagic) eggs. The fertilized eggs then rise above the seasonal thermocline and develop into small larvae that drift with the current as part of the plankton until they are large enough to settle to the bottom and begin life as juvenile fishes. This strategy is employed by most eels, halosaurs, and macrourids (Marshall 1979, Gage and Tyler 1991). Some deep-sea bony fishes produce heavy, demersal eggs with an adhesive membrane that attaches to the substrate or large eggs that are brooded on the seafloor. At the shipwreck site, this strategy was most likely used by eelpouts, sculpins, and ophidiids.

Order Anguilliformes. This order contains 15 families of eels, two of which had representation on the shipwreck: Synaphobranchidae (subfamily Synaphobranchinae – cutthroat eels and subfamily Simenchelyinae – pugnose eels) and Derichthyidae (longneck or serpent eels). Superficially, there is not much variation in the serpentine morphology of eels but over 600 species are recognized. All eels lack pelvic fins and in some species both pelvic and pectoral fins are absent. Both the dorsal and anal fins are joined at the tail forming a continuous fin around the rear of the body. Eel bodies are slimy and either scaleless or covered with minute cycloid scales deeply imbedded in the skin. In most species, the gill openings are reduced to small slits set low on the body in front of the pectoral fins.

All eels share a peculiar life history which includes an extended larval stage. Fertilized eggs develop into large, transparent, leaf-like, leptocephalus larvae. This early life history stage lasts between one and three years. Deep-sea species shed their eggs near the ocean floor. The eggs rise to the upper waters where development takes place (Marshall 1979).

Cutthroat Eel (*Synaphobranchus kaupi*). This eel was first observed in 1988 when a single individual swam into the midst of *Nemo*, eventually colliding with the vehicle's internal rigging. A similar event occurred in 1989, giving the impression that the eel could not see the vehicle. After passing more than a meter into the central portion of *Nemo*, it struck a hydraulic line and immediately swam backwards until free of the submersible. In 1990 a similar eel was again seen, this time in the vicinity of the fish meal trays at a bait experiment station (Table 14). Cutthroat eels live on the soft bottom of the deep continental slope and very little is known of their habits or biology. They were about 40 cm long. The body was scaled and the head was compressed and relatively pointed. The minute scales of all species of this family are arranged in an unusual "basketwork" pattern, with groups of three or four scales lying at right angles to adjacent groups. The teeth are also small and needlelike. In contrast to surface fish, cutthroat eels have a dark-colored ventral region and a pale-colored dorsal region.

Blunt-nosed Eel (*Simenchelys parasiticus*). This small eel with a blunt head is variously known as a "pugnose," "snub-nosed," "monkey-faced," "slime," or "parasitic" eel. This species was not observed at the site until August 1990, when 50 kg of fish carcasses were placed on the ocean floor adjacent to the wreck. Within 43 hours, approximately 50 individuals were photographed, vigorously feeding on the bait (Figs. 120, 121; Table 14). Their feeding behavior consisted of setting their teeth into a carcass and then spinning in a whirling motion until a portion of the flesh was broken loose. Shortly after the feeding frenzy began, a Greenland shark passed through the site and thereafter no more than two eels were observed at the bait experiment station. The experiment was repeated in 1991 but only a few blunt-nosed eels were noted at the station.

These eels averaged about 35 cm in length. The dorsal fin began just behind the pectoral fin and the anal fin origin was about midway down the underside of the body. The mouth was a small slit in the front of the blunt head. The body was gray to brownish-gray with some mottling. Although this fish is reported to be parasitic on other fishes, adults probably cut or rasp chunks of tissue from moribund fishes (Robins and Robins 1976). This species is found worldwide in depths below 500 m.

Longneck Eel (*Derichthys serpentinus*). A small eel-like fish that was believed to be a longneck eel was noted in the feeding trays at the bait experiment station (Table 14). This species was observed in association with eelpouts (*Lycodes zoarchus*) and snub-nosed eels (*Simenchelys parasiticus*) at the experiment station. Literature on this species is scant. Longneck (or serpent) eels were small, deep-water species reaching a length of about 10 to 15 cm. The head was somewhat snake-like, set on a thinner "neck," with large eyes, a short snout, and an underslung lower jaw. The body was somewhat thicker than the neck and was fringed by rather inconspicuous dorsal and anal fins. The horizontal gill slits were set well back on the throat but were well in front of small pectoral fins. The skin appeared to be smooth and scaleless and a uniform brown or gray color. Longneck eels are found at 1,000 to 2,000 m depths and although rare, they appear to be widely distributed, being found in the North Atlantic and South Pacific (Ayling 1987, Nelson 1984). The identification of the this fish as a longneck eel from videotape is tentative. Dr. Daniel M. Cohen viewed the video images and concluded that these very small individuals were quite unique in his experience.

Order Notacanthiformes. This order contains the halosaurs and spiny eels. All 24 species (three families) are eel-like inhabitants of the ocean floor in deep water. Only one family, Halosauridae, was observed on the shipwreck and was represented by *Halosauropsis macrochir*. Members of this family are elongated and have a subterminal mouth. Most of them probably feed on small invertebrates dwelling in soft sediments. Although similar to eels in some respects, they differ by having both pelvic and pectoral fins, a flexible jaw structure, and an elongated anal fin that merges with the caudal fin. In some species, these delicate posterior fins are nearly transparent. The dorsal fin is short and consists of a series of spines. Like true eels, this group produces a large leptocephalus larva which metamorphoses into a much smaller juvenile (Smith 1970). Halosaurs average about 40 cm in length and are gray, brown, or black in color. The scales are relatively large, with fewer than 30 longitudinal rows on either side. They prefer living near the seafloor along the deeper parts of the continental shelf (McDowell 1973).

Halosaur (*Halosauropsis macrochir*). This fish was observed hovering over the seabed and among the ship's timbers in 1989. Typically, the halosaurs were oriented with their heads into the current, merely holding a position or slowly moving. As with the macrourids, they displayed elevated pectoral fins which tended to give them a slight, head-down inclination. They had long, broad anal fins (nearly transparent) which when moved from side to side, tended to lift the tail as well as propel the fish forward. In this position, the snout was probably used for rooting in sediment (Marshall and Bourne 1964). The snout was pointed and overhung the small mouth which readily permitted the underset jaws to seize burrowing animals such as polychaete worms in the sediment ooze. There was also a small dorsal fin in the middle of the body. Although eel-like in appearance, the gill apertures were large, unlike those of true eels, and halosaurs also had pelvic fins which were absent in the eels. An unusual character of these fishes is that the lateral line runs along the lower part of the body (McDowell 1973).

Order Gadiformes. This order contains 10 families and some 700 species of mainly bottom oriented marine fishes. Three families were represented at the shipwreck site: Macrouridae (grenadiers), Moridae (deep-sea cods), and Phycidae (phycis hakes). Gadiform fishes typically have elongated bodies, often tapering to a point at the tail, with long dorsal and anal fins. In some species, these fins are broken up into two or three sections, particularly the dorsal fin. The pelvic fins are either thoracic or jugular in position or they are absent. With the exception of the macrourids which have large scales, all gadiforms have small cycloid scales. Most have large terminal or subterminal mouths, many with barbels. Gadiforms are primarily predators on fish and invertebrates.

Macrourids (*Coryphaenoides* spp.). These were among the most often observed fishes, with sightings from 1987 to 1991. Macrourids are commonly known as rattails or grenadier fish. As suggested in the first common name, they have an elongated, pointed tail formed by the union of the second dorsal, anal, and caudal fins. Some have sizable eyes, a somewhat conical snout, a high first dorsal fin, and a barbel under the chin. Possibly three species were present at the site based primarily on differences in head shape and eye size: *Coryphaenoides armatus* (moderate snout and small eyes), *C. guentheri* (long snout and large eyes) (Fig. 120), and *C. leptolepis* (short snout and small eyes) (Goode and Bean 1895, Marshall and Iwamoto 1973). These macrourids had small scales and moderate pelvic and pectoral fins. They were light gray in color with dark eye sockets. Macrourids are adapted to living near the seafloor on the continental slope. During a bait experiment in September 1990, they demonstrated a voracious appetite by tearing off pieces of the carcasses and by lunging at the fish meal in plastic trays (Table 14). After grasping the flesh by setting their teeth, they would thrash back and forth until a piece was broken free. Often they would then move away from the carcass mound to consume the flesh.

Cods and Hakes (*Antimora rostrata* and *Urophycis chesteri*). Two cod-like fishes were seen cruising past the mound of carcasses at the bait experiment station but neither were observed feeding. The general appearance of these fishes was quite similar with the major superficial difference being the pointed snout of *Antimora* (deep-sea cod) versus the more rounded head of *Urophycis* (blue hake). *Antimora* (family Moridae) had bony ridges that extended back from the tip of the snout to pass under each eye. The first dorsal ray was extremely elongated and the anal fin, like the dorsal, was divided into two parts. The color was a pale blue-gray. Narrow bands of small teeth edge the wide mouth and are used to grasp the free swimming crustaceans and squids that make up the bulk of the diet (Iwamoto 1975). Like all other morid cods, *Antimora* has a swim bladder with two forward projecting sacs that are attached to the back of the skull. These "ear-pods" fit closely against the auditory capsules and may confer extra hearing powers (Marshall 1979). Males have muscles stretched along the side of the air-filled bladder that can be vibrated to produce a loud drumming sound (perhaps to attract females during the spawning season in a dark environment). Male macrourids and ophidiids have similar drumming mechanisms but each species appears to produce distinct sound patterns (Ayling 1987).

Antimora has a worldwide distribution, being found in abyssal depths from 60° N to 60° S latitude. This fish has been observed from 400 m to 3,000 m on the deep continental slope (most abundant from 800 to 1,800 m). This species is one of the most abundant fishes in the abyssal ocean but because of its deep-water habitat and soft flesh, it has not been exploited commercially. Males are much less common than females and do not grow as large, rarely reaching 35 cm as compared with 40 to 60 cm for females. Males seem to live in deeper water, below aggregations of females. Observations from other deep-diving submersibles have shown that morid cods normally hover or swim slowly within a meter or so of the bottom (Ayling 1987).

Urophycis (family Phycidae) was also blue-gray colored with a distinctively long forward dorsal spine. The deeply incised anal fin gave it a double lobed appearance. The dorsal and anal fins extended considerable lengths down the body and closely approached the caudal fin. The pelvic fins were very narrow and elongated. The snout was rounded but flattened on top, and a slender sensory barbel protruded from the tip of the lower jaw. The eyes were moderately large and video images show apparent eye movement. Like most benthopelagic fishes, *Urophycis* swam with a very sinuous movement, holding the pectoral fins out to the side as stabilizers. This style of swimming, while not very efficient, does not give rise to many vibrations in the water for other fish, prey, or predators to detect and does not disturb the fine bottom sediment, even when the fish is almost touching the bottom.

The above identifications were provided by Dr. Tomio Iwamoto and Dr. William N. Eschmeyer, California Academy of Sciences and Dr. Barbara Hecker, Lamont-Doherty Earth Observatory, Columbia University. Alternative identifications were provided by for the gadiform fishes by Dr. Daniel M. Cohen, Natural History Museum of Los Angeles County and Dr. Richard H. Rosenblatt, Scripps Institution of Oceanography. They noted that the member of the family Moridae belongs to either the genus *Laemonema* or the genus *Lepidion*. For the former, the latitude agrees with previous records but the depth is too great by 1,000 m; for the latter, depth is reasonable but the nearest known record is in the vicinity of the Grand Banks, 1,200 km to the north.

Order Ophidiiformes. This order consists four families, only one of which (Ophidiidae) was represented at the shipwreck site. Ophidiids or cusk eels have dorsal fin rays that are equal to or longer than opposing anal fin rays. This family is divided into subfamilies based on the presence or absence of barbels and the type of scales. Subfamily Neobythitinae, the only group of ophidiids observed at the site, has no barbels on the chin or snout and possesses cycloid scales (Nelson 1984). Members of this subfamily were formerly known as brotulids (Goode and Bean 1895).

Ophidiid (*Barathrodemus manatinus*). Ophidiids were perhaps the most ubiquitous fishes on the shipwreck site. The dorsal and anal fins were long and joined with the caudal fin to form the tail which appeared as one continuous fin tapering to a small tuft at the end. The dorsal fin rays were somewhat longer than the opposing anal fin rays. The anal fin's origin was behind the tip of the pectoral fin. Small scales covered the dark bluish-gray, compressed body. *Barathrodemus manatinus* had large fan-like pectoral fins which contrasted with the single-rayed pelvic fins (barbel-like) that were set well forward under the gill opening (Fig. 122). The eyes were relatively large but opaque. Some evidence of a fungal infection was observed on the opercular flap. This normally slow moving fish utilized the modified pelvic fins (presumably equipped with chemosensors) to probe the bottom and detect organic particles in the sediment. The main activity of this fish was noted in areas where decaying wood fragments were abundant. When a suitable particle was found, the fish oriented itself head-down in a near vertical position and lunged, mouth agape, into the sediment penetrating a few centimeters. Backing away, unwanted material was expectorated and desired particles consumed. A similar lunging behavior was observed in August 1991 when a brachyuran crab had captured and was consuming a nereid polychaete worm.

FIGURE 122. Ophidiid fish (*Barathrodemus manatinus*) browsing in sediment on the timbers of SS *Central America* shipwreck.

Barathrodemus slowly approached the feeding crab and when about 10 cm away, it lunged horizontally striking the worm and securing a small portion.

Partially concealed in the collapsed timbers of the shipwreck, a second ophidiid species was observed on a few occasions. The body size was smaller, lighter in color, and the caudial fin did not appear to have a tuft as noted on the larger species. Superficially this fish resembles members of the genus *Neobythites.*

Ophidiids, halosaurs, and sculpins seemed to be the only bony fishes not to approach the carcasses at the bait experiment station. Ophidiids, along with halosaurs, macrourids, and morids show evidence of convergent evolution by the development of wide lateral line canals on the head which contain sensory neuromasts (Marshall 1965). This feature facilitates food detection in the lightless, deep sea.

Order Perciformes. This is a very large order of fishes with 154 families. Only the family Zoarcidae (eelpouts), in the suborder Zoarcoidei, was represented at the shipwreck site. Eelpouts have elongated bodies with long dorsal and anal fins that are confluent with the caudal fin. The pelvic fins, when present, are small and in front of the pectoral fins (Nelson 1984).

Eelpout (*Lycodes*). This fish was first observed in September 1990 at the bait experiment station, arriving about 36 hours after the fish meal trays were deployed (Table 14). Eelpouts were robust, somewhat sluggish fishes that preferred to slither over the bottom or curl up in the meal trays at the station (hence the crew's nickname "garden slugs") (Fig. 121). Because of their bottom preference, they are classified as a benthic species, while most of the other fishes at the shipwreck site would have been considered benthopelagic fishes. However, when prodded, they were capable of actively swimming away from the disturbance. For several days, a number of eelpouts worked the fish meal trays until the meal was depleted. One individual entered a wire-mesh (minnow-type) trap and was recovered. The specimen was presented to Dr. C. Lavett Smith for the collection of the American Museum of Natural History. Dr. Smith identified this species as *Lycodes zoarchus.* From video images of the shipwreck site, Dr. Daniel M. Cohen, Natural History Museum of Los Angeles County, identified feeding eepouts as probably the species *Lycodes atlanticus.*

The eelpouts had elongated, often flabby bodies. The dorsal and anal fins were united with the caudal fin, similar to the fin arrangement of the ophidiids. The pectoral fin of *Lycodes* was enlarged, giving rise to another common name, "eared eel." The mouth was subterminal (downward-pointing), typical of bottom-feeding fishes, and the head was blunt with relatively large eyes (Fig. 123). The recovered eelpout was limp with a loose, delicate skin that was purple-gray and somewhat patterned, that became paler on the ventral side. Scales seemed to be absent. The eelpout lacked a swim bladder, reflecting its benthic life style. Thus, when the specimen was brought to the surface, the pressure changes did not have any apparent adverse effect on the form of the animal's body.

FIGURE 123. An eelpout (*Lycodes zoarchus*) cruises over the seabed of pteropod ooze. At the upper left a blunt-nosed eel (*Simenchelys parasiticus*) feeds on a fish carcass (mackerel) from a bait experiment and at the lower right a brittle star (*Bathypectinura heros*) snakes over the ooze.

Order Scorpaeniformes. This order contains six suborders and 21 families. One suborder (Cottoidei – sculpins) and within it one family (Psychrolutidae – fathead sculpins) was observed at the shipwreck site. Fatheads are a group of rather obscure sculpin-like species which are thought to be intermediate between true sculpins (Cottidae) and snailfishes (Cyclopteridae: Liparinae). They are small individuals that have a low first dorsal fin which is not differentiated from the second dorsal fin and loose prickly skin (Wheeler 1975).

Deep-sea Sculpin (*Cottunculus thompsoni*). This deep-water species was observed in the debris field adjacent to the shipwreck in 1989. As the submersible *Nemo* was conducing a reconnaissance survey of the area, it approached within a meter of the ocean floor on which a piece of copper sheathing from the hull was partially buried. The displacement of the submersible generated a surge which rooted a sculpin-like fish from its hiding place under the metal. The fish scooted along the bottom with the current, suggesting it did not possess a swim bladder. Adult sculpins, including *Cottunculus thompsoni* which this individual resembled, do not possess swim bladders (Fritzsche and Fuiman 1982, Marshall 1979) and are adapted to a benthic habitat. The individual captured on videotape was about 25 cm long and light brown in color with darker and enlarged pectoral fins. Its tadpole-shaped, flat head occupied nearly one-third of its total body length. The body skin appeared lax and scaleless and the head was composed of plates bearing blunt spines. The eyes were fairly large and set high on the head.

COMMUNITY ECOLOGY

Bruun (1956) defined the fauna that exits in the deep sea from the edge of the continental shelf to a depth 2,000 m as "bathyal;" the fauna from 2,000 to 6,000 m as "abyssal;" and the fauna of the oceanic trenches as "hadal." The benthopelagic zone is inhabited by animals that swim within a few meters above the seafloor, whereas the benthic zone is inhabited by infauna (burrowing animals) and epifauna (animals on or just above the substrate). Off the coast of the southeastern United States, the abyssal faunal province is defined as commencing with the start of true abyssal sediments (e.g., foraminiferal ooze), the 4° C temperature isotherm, and bottom water transported by the Deep Western Boundary Current (Menzies et al. 1973). Topographically, it includes most of the continental slope, all of the continental rise, and the abyssal plain. It ranges in depth from 1,000 to 5,000 m. The upper abyssal zone (1,000 to 2,600 m) is located entirely on the continental slope and included the location of the SS *Central America* shipwreck.

Community Structure

In the deep-ocean realm, most of the organic matter is produced and consumed at the surface but some of this food is used all the way down to the bottom. As plankton settles, there is a steady reduction in its biomass on the way down as it is eaten by predators. At 1,000 m, the plankton is only one-tenth as plentiful as it is near the sea surface. Below this depth, the number of organisms decrease at a steady but slower rate until there are few remaining just above the deep-ocean floor. Most of the food supply to the bottom consists of detritus from above. As the detritus continues to sink, it is consumed by deeper and deeper animals or broken down by bacteria so that only a small fraction reaches the seabed. Thus, one would not expect the deep ocean to be teeming with animals. However, the shipwreck of the SS *Central America* was a biological oasis, particularly for macroscopic animals, in the midst of a deep-ocean desert. The shipwreck provided an unusual substrate, including wooden timbers, coal, and metalworks, which had been colonized by a diverse group of animals (Table 16). The conspicuous members of the community included: hexactinellid sponges, gorgonian corals, sea anemones, polychaetes, pholadid bivalves, benthic molluscs, isopods, decapods, amphipods, barnacles, crinoids, sea stars, holothurians, and benthopelagic fishes. The hull area of the shipwreck was blanketed with a thin layer of pteropod ooze, whereas the surrounding sediment was a foraminiferal ooze. The abyssal organisms present on the shipwreck site and the surrounding continental slope can be classified in four large groups based on their size, independent of their taxonomic relationships: 1) megafauna, 2) macrofauna, 3) meiofauna, and 4) microfauna.

Megafauna. This group consists of those large animals which cannot be sampled adequately with a grab technique for quantitative evaluation (Grassle et al. 1975). The taxa of the megabenthos include certain groups of sponges, anthozoans, amphipods, decapods, cephalopods, crinoids, asterozoans, ophiuroids, echinozoans, holothurians, and fishes. Some of them may be caught in trawls but others can escape dragged gear. Photographic surveys can provide site specific and spacial relationship information of never or rarely seen species. Scavengers may be attracted to baited traps or to deployed carcasses and can be recovered or photographed in this manner. Perhaps the most desirable method of sampling the sessile megafauna is using the manipulator of a robotic submersible such as *Nemo*. Target specimens can first be photographed in their natural habitat and then carefully collected and placed in sealed containers for transport to a surface research vessel. During the present study, specimens were obtained by viewing closed-circuit color television monitors (some of which presented stereoscopic images) in the control room of the surface research vessel and directing the submersible to make the collections. Deep-sea animals recovered in this way came to the surface in excellent condition without the damage often inflicted by other techniques.

Macrofauna. This group includes metazoans of over 1 mm in size, such as sponges, corals, sea anemones, polychaete worms, molluscs, crabs, isopods, sea cucumbers, sea urchins, feather stars, and sea stars. Several recent investigations of macrofauna in western North Atlantic Ocean sediments at depths between 1,800 and 2,200 m showed densities for individuals that ranged from about 4,000 to 5,000/m^2 (Grassle and Morse-Porteous 1987). Similar macrofaunal densities were anticipated in the undisturbed foraminiferal ooze surrounding the shipwreck. In considering the features of the deep-sea environment that determine community structure and that maintain a high diversity of species, they concluded the following to be the most important: 1) patchiness of organic input against a background of low productivity, 2) sporadic, small-scale, discrete disturbance events occurring against a background of relative constancy, and 3) the lack of barriers to the dispersal among populations distributed over an enormous area. Organic input, such as the sinking of a large wooden ship, represents a source of disturbance for existing populations, as well as, a new habitat for growth of other populations.

The location of greatest faunal change for the upper slope of the western Atlantic Ocean coincides with the latitude of the boundaries between warm-temperate and cold-temperate faunas of the shelf which lies off Cape Hatteras, NC (Briggs 1974). Vinogradova (1959, 1962) found that the changes in systematic composition of the bottom fauna were most pronounced at a depth of 3,000 m. Here a large number of species, genera, and even families characteristic of the slope disappear and are replaced by groups peculiar to the greater depths. Epibenthic sled samples of benthic invertebrates (infauna and epifauna) yielded the following numbers of individuals (Sanders et al. 1965):

outer continental shelf	6,000-13,000/m^3
upper continental slope	6,000-23,000/m^3
lower continental slope	1,500-3,000/m^3
abyssal	<1,000/m^3

Thus, at increasing depths, researchers have found fewer and fewer macrofaunal individuals even though physical conditions were found to be more and more stable. However, Grassle and Sanders (1973) found high diversity in certain instances, indicating that the number

TABLE 16

Habitat preferences of taxa found in the deep ocean on the shipwreck of the SS Central America.

Organism	Water Column	Sediment Ooze	Ship Wood	Iron/ Rust	Coal	Gold	Leather	Pottery/ Glassware	Nonferrous Metals	Textiles	On Other Organisms
Sargassacean brown algae		•	•								
Diatoms & Coccolithophores						•				•	
Foraminiferans		•									
Radiolarians		•									
Demosponges			•	•			•				
Hexactinellid sponges		•	•	•			•				
Tubulariid hydrozoans				•							
Siphonophores	•										
Scyphozoans	•			•							
Alcyonacean corals			•	•							
Gorgonacean corals			•	•	•	•	•				
Actiniarian sea anemones			•			•	•	•			•
Scleractinian corals				•							•
Antipatharian corals			•								
Ctenophores	•										
Nematodes		•									
Sipunculans		•									•
Mytiloid bivalves		•									
Veneroid bivalves		•									
Pholadid bivalves		•	•								
Teredinid bivalves		•	•								
Cuspidariid bivalves		•									
Trochid gastropods		•									
Janthinid gastropods		•									
Turrid gastropods		•									
Cylichnid gastropods		•									
Bullid gastropods		•									
Heteropods		•									•
Pteropods	•	•									
Bathypolypod octopods	•	•	•								
Nereid & Polynoid worms		•									
Eunicid worms		•									
Chaetopterid worms			•					•			
Serpulid worms				•	•			•		•	
Pogonophorans			•	•					•		
Aegid isopods	•	•									
Lysianassid amphipods	•		•								
Carid shrimps	•		•								
Galatheid crabs		•	•	•	•	•			•		•
Parapagurid crabs		•									•
Geryonid crabs		•	•								
Lepadid barnacles											•
Scalpellid barnacles			•								
Verrucid barnacles									•		
Bryozoans											•
Brachiopods		•			•	•		•			
Bouergueticrinid crinoids					•						
Comatulid crinoids			•		•	•					•
Astropectinid sea stars		•									
Echinasterid sea stars			•								
Pedicellasterid sea stars			•			•					
Brisingid sea stars		•	•	•		•			•		
Ophiurid brittle stars		•									
Asterostomatid heart urchins		•									
Echinothurid sea urchins		•									
Chiridotid sea cucumbers		•	•		•						
Synallactid sea cucumbers		•									
Deimatid sea cucumbers		•			•						
Enteropneusts		•									
Stolidobranchian tunicates		•			•						
Rajid skates	•										
Squalid sharks	•										
Chimaerid sharks	•										
Anguilliform eels	•										
Halosaurid fishes	•										
Macrourid fishes	•										
Morid fishes	•										
Ophidiid fishes	•		•			•					
Zoarcid fishes		•									
Psychrolutid sculpins	•	•									

of deep-sea species had gradually increased as they adjusted to each other and assumed narrower and more specialized niches within a stable environment, opening underutilized resources to exploitation. The high diversity observed at the shipwreck site appears to be an example of this process.

Meiofauna. This group comprises metazoans smaller than 1 mm in size but larger than single-celled organisms that live on the ocean floor or in the sediment (Higgins and Thiel 1988). They include nematodes, amphipods, ostracods, copepods and the juvenile forms of the macrofauna. On bottoms without appreciable currents, much of the fauna lives on the surface, whereas if moderate or strong currents are present, the fauna tends to burrow (Thistle et al. 1985). Nematodes typically dominate the meiofauna in sediment biotopes, followed by harpacticoid copepods (Coull 1988). Deep-sea abundance is usually an order of magnitude lower than shallow water.

Tietjen (1971) studied the ecology and distribution of meiobenthos occurring on the outer continental shelf and continental slope at depths from 100 to 2,500 m off the Carolina coast. Sediments of the upper region (100 to 500 m) consisted of medium-sized calcareous sands with relatively low organic contents, while the deeper sediments (1,000 to 2,500 m) consisted of sandy silts with higher organic carbon components (Table 17). Two basic faunas were present: 1) a shallow-water (100 to 500 m) dominated by nematodes with significant numbers of harpactacoid copepods, ostracods, benthic foraminiferans, polychaetes, and gastrotrichs and 2) a deep-water (1,000 to 2,500 m) fauna where only nematodes and foraminiferans are present in large numbers (Table 18). The species composition and abundance of nematodes and benthic foraminiferans for the two depth ranges are highly correlated with changes in sediment composition, organic content, and bottom water temperature. Although finer sediments and high organic content appear to enhance the populations of these meiofauna groups, the low temperatures below 2,000 m may tend to suppress them, or at least cause a shift in species composition. A total of 212 species of nematodes belonging to 23 families was identified by Tietjen (1971) along the Carolina transects. Of these, 24 species were found in the depth range of the SS *Central America* shipwreck, 2,000 to 2,500 m (Table 13). Nematodes at these depths are only 10% of those found on the continental shelf and ranged from 32,000 to 56,000/m^2 of sediment. This value appears to be representative of such depths as demonstrated by similar population numbers off East Africa (Thiel 1975). About 95% of the meiofauna, including the nematodes, occurs in the upper 1 to 2 cm of sediment regardless of sediment type and depth.

At the depth range of the SS *Central America* shipwreck, the nematode feeding types were highly correlated with the sediment character and availability of food. Here, deposit feeders constitute about 80% of the nematode fauna, while predators/omnivores and epifaunal feeders make up only about 12% and 8%, respectively. For deep-sea nematodes and benthic foraminifera, there are essentially two main sources of food: 1) detritus (either derived from the euphotic zone or formed *in-situ*) and 2) bacteria. The sources of detritus are uncertain but several are possible. Bottom photographs taken by Rowe and Menzies (1968) off the Carolina coast show that the slope from 600 to 2,500 m is a zone of deposition. Tietjen (1971) indicates the occurrence of salt-marsh grass in these sediments out to a depth of 2,000 m. This suggests that marsh grass and other shallow-water detritus originating in coastal areas to the north are being washed out to sea, sinking, and are transported to the south by the Deep Western Boundary Current to be deposited on the

TABLE 17

Physicochemical data on the continental shelf/slope off the Carolina coast.

Depth (m)	Water Temp (°C)	Sediment: Median Size (mm)	Sediment: Organic Carbon (%)	Sediment: Calcium Carbonate (%)
100	20.0-24.0	0.50 (sand)	0.1	56.2
1,000	4.5-4.8	0.02 (silt)	1.5	52.5
1,500	3.8-4.3	0.01 (silt)	1.2	56.5
2,000	3.4-4.0	0.01 (silt)	1.0	63.3
2,500	3.2-3.8	0.01 (silt)	1.1	71.6

Note: Bottom water temperatures are approximate annual range.
Data Source: Tietjen (1971).

TABLE 18

Meiofauna found in sediments off the Carolina coast at depths of 100 to 2,500 m (number per 100 cm^2).

Meiofauna Group	Depth in Meters: 100	1,000	1,500	2,000	2,500
Nematoda	228	79	86	56	32
Foraminifera	139	617	400	310	195
Polychaeta	19	4	1	1	2
Ostracoda	20	3	3	1	3
Rotifera	51	4	10	1	4
Harpactacoidea	41	2	2	2	1
Gastrotricha	14	0	0	0	0
Nauplii larvae	24	3	6	3	1
Others	29	3	0	0	0
Totals	565	715	508	374	238

Note: Counts were made on cores and box dredge samples to a depth of 10 cm, thus the above data can also be interpreted as numbers of meiofauna per 10 cm^2.

Data Source: Tietjen (1971).

continental slope. Menzies and Rowe (1969) speculate that turtle grass (*Thalassia testudinata*), which originates off Florida, is carried north by the Gulf Stream and then south by undercurrents to also accumulate in this region. *Sargassum* seaweed has also been observed on the ocean floor at the wreck site, at times in sizable mats. These grasses and algae may then be consumed directly by bottom herbivores but more likely they serve as substrate for bacteria which are in turn eaten by the nematodes, foraminiferans, and other meiofauna. Ophiuroids, seen in photographs of the soft sediment surrounding the shipwreck, were one of the likely predators on the meiofauna at the site.

Deep-sea meiofauna are primarily detrital feeders or indiscriminate feeders on bacteria. Both nematodes and copepods are known to produce mucus to trap bacteria and ingest the mixture (Riemann and Scharge 1978). There is evidence that meiofauna play an important role in making detritus available to macroconsumers (Tenore et al. 1977). Eelgrass detritus was consumed by polychaetes at nearly twice the rate when meiofaunal organisms were introduced to a culture. However, the factors causing this increase are not clearly understood but are believed to be related to an enhancement of microbial activity.

In recent years, a number of papers have been published which document the presence of meiofaunal prey in the stomach contents of marine fish and invertebrate predators. Benthic copepods are overwhelmingly selected over other available prey, particularly surface floc dwellers (Higgins and Thiel 1988). Meiofauna appears to serve as food for higher trophic levels more often when the bottom is mud rather than sand. In mud-detrital substrates, most of the meiofauna are restricted to the top-most sediment layers and an indiscriminate browser/ingester would inevitably collect the resident meiofauna. Platt (1981) has proposed a benthic meiofaunal food web that includes macrofauna, meiofauna, swimming predators, and meiofaunal food (e.g., bacteria, detritus, protozoans, and dissolved organic matter). Meiofauna can be eaten by swimming predators (e.g., fishes and shrimps), deposit feeders (e.g., polychaetes and holothurians), or by suspension feeders (e.g., molluscs and cnidarians) if the meiofauna is suspended.

Meiofauna have adaptations for remaining in close proximity to the bottom. Pelagic larvae are virtually nonexistent. Development and morphology seem designed to ensure that the organism remains on the substrate (Sterrer 1973). One would expect limited distribution patterns but numerous species are cosmopolitan; the mechanisms creating pan-oceanic and worldwide meiofaunal distribution are poorly understood. Possible dispersal mechanisms include: 1) plate tectonics, 2) via airborne animals, 3) rafting on drifting material, 4) transported in ballast of sailing vessels, and 5) dispersal by suspension in the water column. The latter, and perhaps the most important, is primarily a passive process resulting from mechanical removal by current scour; the abundance of meiobenthos in the water column at any one time appears to be a function of the magnitude of the current velocity (Gerlach 1977, Palmer and Gust 1985). However, some meiobenthic copepods have been shown to actively migrate into the water (Walters and Bell 1986).

Microfauna. The smallest group, the microfauna, contains the bacteria, fungi, ciliates, and other one-celled organisms, particularly benthic foraminiferans. These communities have been discussed in some detail in other sections of this paper (see Microorganisms and Phylum Protozoa) and will be further discussed later (see Iron Degradation and Textile Degradation in Materials Science section).

Community Analysis. An uncontrolled mosaic of photographs of the shipwreck at Site D-2 (approximately 50 km northeast of the SS *Central America* site) was analyzed for community structure and population density. A number of taxonomic groups within the megafauna and macrofauna were readily recognizable in the images, including: 1) hexactinellid sponges, 2) gorgonian corals, 3) tubes from wood-boring bivalves, 4) galatheid crabs, 5) brisingid sea stars, 6) six-armed sea stars, and 7) benthopelagic fishes. Numerous impressions were also visible in the sediment ooze adjacent to the vessel. The shipwreck appeared to be a wooden-hulled sailing vessel about 20 m long and 8 m wide.

The mosaic was divided into 35 cells, each 3 m on a side (Fig. 124). The number of individuals for each taxonomic group was estimated for each cell (Table 19). Hexactinellid sponges were the most abundant, comprising about 66% of the community members. Expressed in terms of density, the approximate 90 m^2 area inside the hull contained 235 sponge colonies or 2.6/m^2. Galatheid crabs and gorgonian corals were the next in abundance, accounting for 17% (0.7/m^2) and 14% (0.6/m^2), respectively. Brisingid sea stars were only 3% with a density of 0.1/m^2. The six-armed sea star (*Ampheraster alaminos*) and macrourid or ophidiid fishes were represented by only a few individuals. The calcareous tubes of wood-boring bivalves were abundant within the hull area and numerous biogenic impressions (e.g., curved furrows and "fairy rings") were noted in the sediment surrounding the vessel, particularly on the port side. Most of the groups appeared to be uniformly distributed throughout the shipwreck.

Productivity and Food Webs

Food Resources. Excluding the animals associated with hydrothermal vents, the benthic fauna of the deep sea is energized by organic matter that either falls from above or is swept down the continental slope (Marshall 1979). At a depth of 2,050 m in the Tongue of the Ocean off the Bahamas Islands, sedimentation traps collected an average daily accumulation of about 50 mg/m^2 of organic carbon when adjusted for losses (Wiebe et al. 1976). Primary productivity in this area is estimated at 300 mg C/m^2, which is similar to estimates for the euphotic zone above the SS *Central America* shipwreck (Cushing 1975). Thus, perhaps 17% of the carbon fixed in the euphotic zone reaches the abyssal floor by falling through the water column. Studies by Bishop et al. (1977)

at a deeper station off Liberia (4,000 m) indicated that only 13% of organic carbon fixed by photosynthesis reached the abyssal floor. Thus, the estimates derived from the work of Wiebe et al. (1976) and Cushing (1975) seem reasonable. These studies showed that amorphous fecal pellets compose the bulk of the organic matter that accumulates on the abyssal floor at depths of 2,000 to 4,000 m and that it takes from five to 15 days to fall to these depths.

Suspended organic particles in seawater, the product of decaying life from the euphotic zone, scatter light and produce turbidity which decreases from the surface to a "clear water minimum" at depths between 1,000 to 3,000 m. At depths similar to the shipwreck site, Biscaye and Eittreim (1977) found concentrations of suspended particulate matter that typically averaged only 2 to 3 µg/l. In deeper water (>3,000 m), they found that near the seafloor the turbidity increased about 10-fold.

Annual Production. By enumerating abyssal organisms per square meter of the seafloor and relating these data to the number of generations in a year, the annual production of living material (expressed as carbon) can be estimated. Using this technique, Thiel (1976) determined the following "order of magnitude" estimate for the four major deep-sea groups:

	Production (g C /m^2/yr)
megafauna	>0.1
macrofauna	0.2-0.5
meiofauna	1.0
microfauna	8.0

Considering that microfauna would be the expected food for the meiofauna and these in turn would be eaten by the macrofauna, the relative size of the estimates are reasonable. However, many of the animals in the various size groups may feed on the same food source (i.e., sinking organic debris).

Food Webs. Thiel (1976) proposed the generalized abyssal food chain diagram (Fig. 125) to represent the complex food webs on the deep-ocean floor. The bacteria utilize not only the organic matter brought in from other parts of the ocean but also that from the decaying bodies of the resident meiofauna and macrofauna. The existence of fungi on decomposing organic material is suspected but its role in the deep sea is uncertain. In both the meiofauna and the macrofauna, there are organisms which can take up dissolved organic substances through their body surface but most feed primarily on living and dead organic matter in the sediment or suspended in the bottom waters.

Abyssal animal communities appear to have evolved to take advantage of detrital food supplies. Typically, the bottom is soft and inhabited by animals that live on or in it and take in sediment and other bottom animals as food. Worms of various phyla, sea cucumbers, and molluscs are the dominant groups. Animals which catch floating food particles are usually rare in the deep sea. However, the shipwreck of the SS *Central America* provided habitat structure and nutrition in the form of decaying wooden timbers. As a result, the community was similar to that which might be expected at depths of less than 500 m, being largely of animals that catch prey floating in the water. Chief among these were sponges, cnidarians, feather stars, and sea stars.

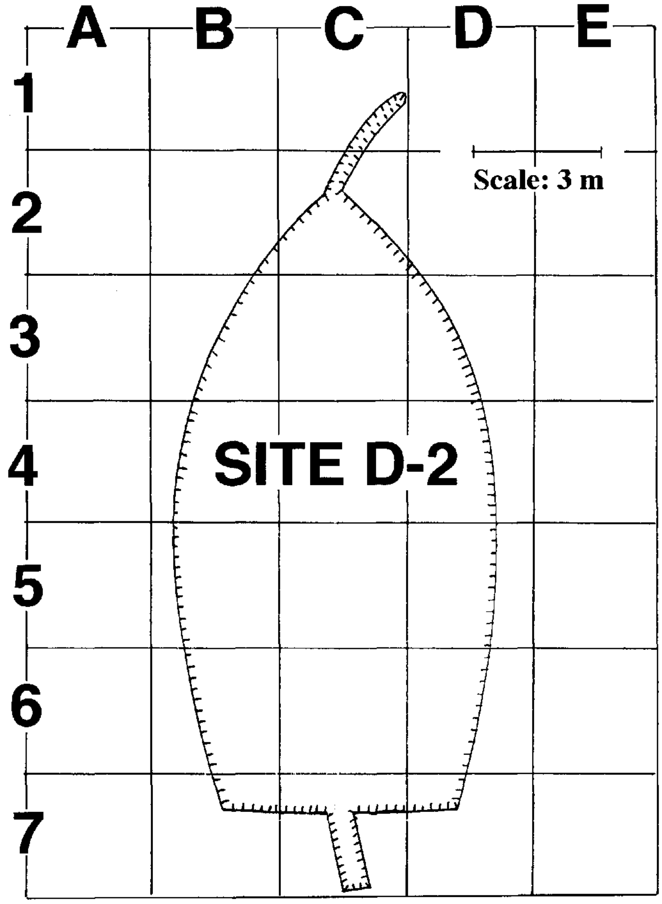


FIGURE 124. Grid established on an uncontrolled photomosaic of the shipwreck found at Site D-2. The benthic fauna enumerated from the mosaic are listed in Table 19.

The shipwreck of the *Central America* fostered a deep-sea ecosystem quite different from the monotonous foraminiferal ooze which surrounded the wreck for many kilometers. The wooden hull and decks, the massive ironworks, and the abundant piles of boiler coal provided diverse habitats for an intricate food web ranging from bacterial decomposers of wood, seaweed, and animal remains to large piscivorous sharks. Preliminary examinations of the deep-sea fauna of the site revealed seemingly complex interrelationships. However, a simple conceptual model can be employed to describe how the food web of this ecosystem functions and to trace the flow of energy, in the form of food, through this web (Fig. 126). As in most deep-ocean animal communities, the primary source of food is from the overlying surface waters of the ocean. Plant detritus, fecal pellets, and animal carcasses slowly drift to the seafloor where decomposers reduce them to more simple organic compounds or browsing animals consume them directly. Two deviations from this generalized pattern have been observed at the wreck. First, the timbers of

TABLE 19

Benthic fauna photographed at Site D-2.

Cell No.	Hexactinellid Sponges	Gorgonian Corals	Wood-borer Tubes	Galatheid Crabs	Brisingid Sea stars	Worm Trails
A-1						W
A-2						W
A-3						W
A-4						W
A-5						W
A-6						W
A-7						W
B-1						W
B-2				2		W
B-3	23	5		6		W
B-4	21	6	B	2		W
B-5	16	2	B	3		W
B-6	23	1	B	1		W
B-7	2					W
C-1	2	1		1	1(F)	
C-2	17	5	B	9	1(F)	W
C-3	11	1	B	5		
C-4	23	6	B	6	1(M)	
C-5	13	3	B	3		
C-6	12	1	B	1	2(F)	
C-7	7	2	B		3(F)	W
D-1						
D-2	2	2				
D-3	11	6	B	3		
D-4	15	4	B	5	1(F)	
D-5	18	2	B	7		
D-6	15	3		3		W
D-7	4	1		1		W
E-1						
E-2						
E-3						
E-4						
E-5						
E-6						W
E-7						W
Total	235	51		59	9	
Percent	66%	14%		17%	3%	

Note: Cell size: 3 m x 3 m = 9 m^2 (Cell locations on Fig. 124).
B = Numerous wood-borer tubes.
W = Abundant biogenic impressions in the sediment.
F = Female brisingid sea stars.
M = Male brisingid sea star or comatulid feather star.
Not listed above:
Three 6-armed sea stars (*Ampheraster*): (Cells C-4, D-3, and D-5).
Two fishes: (Cells C-3 and C-7).

the *Central America* had been heavily infested with deep-sea shipworms, largely of the genera *Xylophaga* and *Xyloredo*. These wood borers derived a significant portion of their nutrition from the wood cellulose which they consumed. They were also capable of filtering organic material suspended in the water to supplement or even replace their wood diet. These bivalve molluscs were in turn consumed by more errant benthic predators as the abyssal food chain progressed (Fig. 126).

The second departure from the normally slow process of plant detritus settling to the seabed appeared to be a rapid physical transport of seaweed from the ocean surface during major storm events. Throughout the summer of 1989, large drifting mats of the brown algae, *Sargassum*, were observed from the decks of the *Arctic Discoverer*, at the western edge of the Sargasso Sea but no accumulation of this seaweed was noted on the seafloor until late September. Hurricane Hugo passed

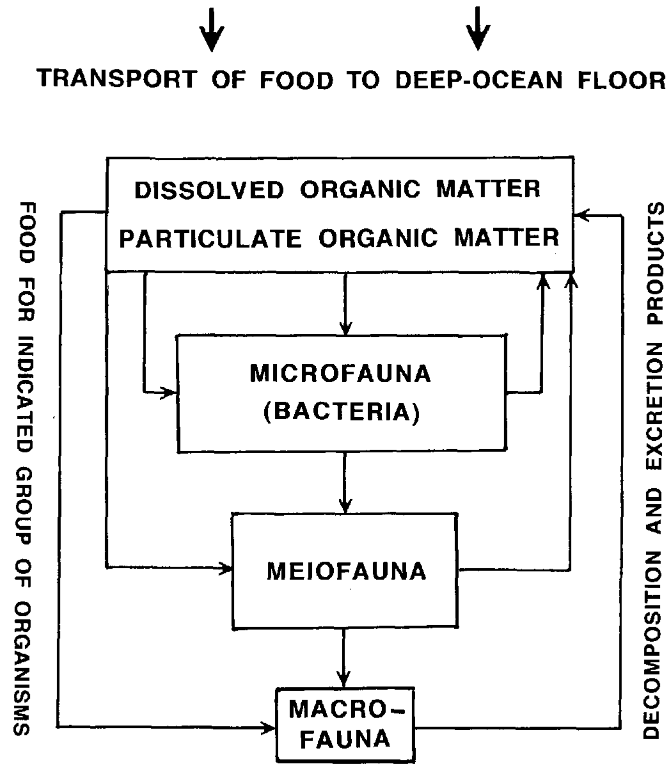


FIGURE 125. Food chain diagram for the deep-ocean floor. After Thiel (1976).

directly over the recovery site on 20 September and the *Arctic Discoverer* was forced to seek safe refuge in Wilmington, NC. On 27 September, the seas had quieted to the point where submersible operations could be resumed. On the first dive, numerous "tumbleweed-like" patches of *Sargassum* were observed on the ocean bottom. The *Sargassum* appeared "fresh" in both video observation and in samples retrieved by the research submersible *Nemo*. A tentative conclusion is that the *Sargassum* was transported to the bottom by storm-generated, down-welling currents, perhaps initiated by Langmuir circulation. It is conceivable that as the eye of the hurricane (characterized by extremely low pressure) passed over the site, the ocean surface was mounded upward, a phenomena that has been observed in other hurricanes. Once the eye had passed, gravity (geostrophic) currents would have been generated downward to correct the imbalance in the sea surface. These may have given rise to the transport mechanisms which carried the seaweed to the seafloor. In any case, the delivery of this plant material to the seafloor provided an important source of energy to the benthic ecosystem.

Succession. When the SS *Central America* sank to the ocean floor, it is likely that most of the dominant species in the impact area were eliminated and with the introduction of an entirely new set of substrates, the biotic environment was radically changed. The opportunity for certain species (formerly constituting only a minor part of the benthic community or for outside species) to colonize the shipwreck was created. McConnaughey and Zottoli (1983) point out that eventually, even if an area is not further disturbed, the interactions between the pioneer species and the gradual re-establishment of dominant species best suited to the area will produce a succession leading to the reestablishment of a so-called climax or mature community. In this process, certain pioneer species may be eliminated or regulated to minor positions.

An example of this process could be seen in the apparent early invasion of Xylophagainae molluscs. These wood borers converted the wood to fecal pellets that were eaten by detritus feeders. As the wood disintegrated, the boring molluscs were preyed upon if alive and scavenged if dead (Turner 1973). The borers completely riddled the ship's timbers but no live specimens were found in the wreckage. Other colonizers of hard substrates, e.g., hexactinellid sponges, galatheid crabs, and brisingid sea stars, now dominate the shipwreck. But these species, will most likely give way to formerly dominant sediment dwellers as the wreckage continues to deteriorate.

Deep-Ocean Adaptations

As a habitat, the deep ocean is distinguished by a high degree of uniformity and stability. The water temperature varied only a degree or two annually at the shipwreck site. Approximately 85% of the ocean floor (or 60% of the entire surface of the earth) lies at depths in excess of 2 km. Below this depth, the sea takes on special characteristics. There is no sunlight and living green plants are absent. This huge realm is far removed from direct inputs of organic sources of energy. The water is cold, with an average temperature of 3 to 4° C and oxygen levels are maintained at 5 to 6 ml/l. Thus, the abyssal seafloor is perhaps the largest near-constant environment on earth.

Deep-sea experiments conducted over the last two decades revealed that no bacteria are specifically adapted to seafloor conditions greater than 2,000 m. Bacteria exist at such depths and much deeper but the effects of increased pressure and low temperature appear to cause a slowdown of microbial activity as compared to decompressed populations held at equal temperatures. Jannasch et al. (1976) observed no truly barophilic response (higher rates of growth at pressures greater than one atmosphere) in their deep-sea experiments. For example, microbial populations at depths ranging from 1,800 to 3,130 m (100 to 313 atm) showed a rate of activity 5 to 60 times slower, as measured by amino acid utilization, than the same populations at 1 atm. Such results are likely to apply to microbial degradation of pollutants wherever they reach the ocean floor. They also indicate that a substantial accumulation of certain materials might occur in deep waters. Dilution also affects microbial degradation in that decomposition of substrates is slowed down significantly if bacteria are diluted beyond a critical point (Jannasch 1979).

These studies have demonstrated that metabolic rates of deep-sea bacteria are much lower at pressures normally experienced on the seafloor than at sea surface pressures but less is known about the response of multicellular organisms. Deep-sea pressures may be sufficient to alter enzymatic reactions. Sumich (1992) reported

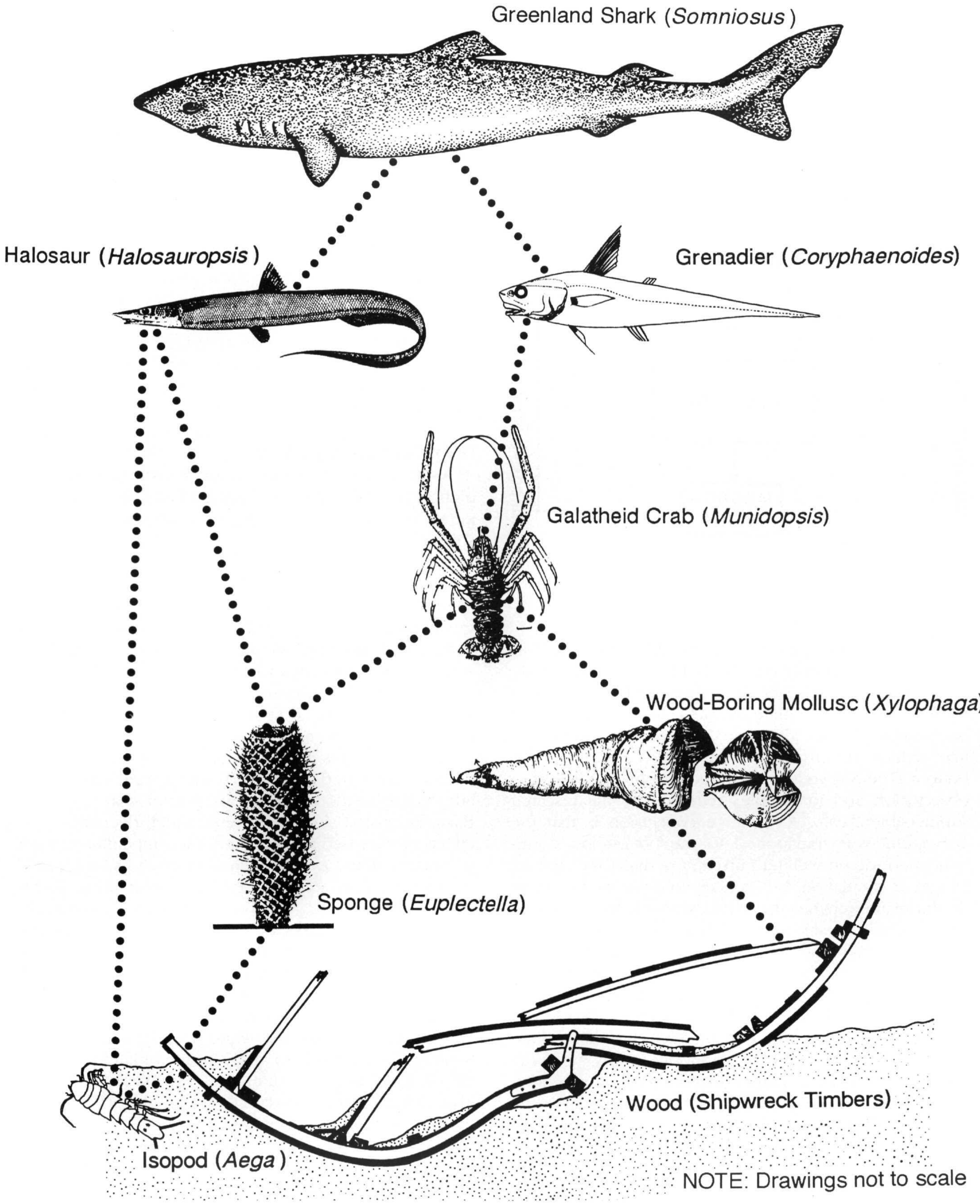


FIGURE 126. Simplified deep-sea food web based on shipwreck timbers at the SS *Central America* site.

some pressure-induced reductions in metabolic rates that led to lowered growth and reproductive rates but increased life spans in the deep sea. The occasional gigantism found in some deep-sea species may be related to metabolic adjustments to extreme pressures.

Because of the permanent darkness, most of the crustacean and fish species observed on the shipwreck appeared to have small, weak, or even non-functional eyes. To compensate for this, they have an especially well-developed tactile sense. In crustaceans, particularly the galatheid crabs and amphipods, the tactile organs and sensory hairs are frequently located on elongated legs and antennae. Presumably, they serve to detect water current and pressure waves indicative of the presence of food or predators. Epibenthic crustaceans of the deep sea, such as the shrimp *Nematocarcinus ensiferus*, have long, slender appendages, and a low metabolic rate (Agassiz 1888). In deep-sea fishes, tactile sensors are concentrated either in the barbels, which are often branched as in the ophidiids, or in the elongated rays of the dorsal, ventral, and tail fins. The elongated caudal fin of the halosaur, *Aldrovandia*, is used for propulsion while the long, broad anal fin, projecting snout, and inferior mouth are adaptations for rooting in the soft ooze. Deep-sea photographs of rattails on the continental slope (2,600 m deep) off New York confirm that they root in the sediment ooze (Marshall and Bourne 1964). Inspection of their stomachs shows that much of the rattails' diet consists of small, burrowing invertebrates such as polychaete worms and various crustaceans. Of all the environmental factors in the deep-sea habitat, as evidenced by structural adaptations of most of the animals, food supply is the most important.

The animals of the deep-ocean floor are certainly a distinctive group but few exhibit structural adaptations that make them appear notably different than their shallow-water relatives. However, in the harsh but physically stable deep-ocean environment, patterns of reproduction are notably different than those of shallow-water benthic animals. Few deep-water species, except some strong swimming fish, produce planktonic larvae. Fewer but larger eggs are produced, which increases their survival rate in an area with a limited external food supply.

Food for deep-sea benthic communities is repeatedly consumed by pelagic scavengers and bacteria as it sinks from the surface. The fallout of fecal particles is an important transport mechanism for organic material to reach the abyss. Such particles may reach the ocean floor in a few days, versus weeks or months for the settling of smaller plankton. Large, rapidly sinking masses, including fishes, squid, and an occasional cetacean, may provide a significant, although unpredictable supply of food to the deep seafloor. Such items are eaten by a wide array of scavenger-predators, which seem to be food generalists capable of quickly locating and consuming large food items. However, it took several days before galatheid crabs and sea stars entered traps baited with beef and lobster on the *Central America* site, perhaps indicating that food resources were not scarce on the shipwreck.

Some of the food from large carcasses is eventually dispersed as detritus and fecal waste to other components of this benthic community. A portion of this and smaller edible material settling to the bottom is immediately claimed by suspension feeders, particularly on hard bottoms such as those presented by the coal, wood, and metalworks of the shipwreck. Away from the wreck, in the soft sediment ooze, the majority of benthic animals are infaunal deposit feeders. The term "cropper" was been used for deep-sea animals that have merged the roles of predator and deposit feeder (Dayton and Hessler 1972). These croppers, by heavily preying on populations of smaller deposit feeders, may be responsible for reducing competition for food and for permitting coexistence between species sharing the same but limited food resources.

Hydrostatic pressure increases with depth at a rate of 1 atm/10 m. This means that animals living at 2,200 m are under a constant pressure of 220 atm. This had no effect on the shape of the invertebrates living on the shipwreck since there was no air-filled space in their bodies. Body fluids have extremely low compressibility, so that physically deep-sea animals can withstand the high pressures with no difficulty. If marine animals contain gases, changes in pressure can have marked effects. The benthopelagic fishes on the site that have swim bladders were probably limited to relatively narrow depth excursions.

Benthopelagic and Benthic Fishes

Images from the shipwreck of the *Central America* confirmed earlier reports of observers in undersea vehicles and deep-ocean photographs that diverse fishes habitually swim near the deep seafloor (Marshall 1971) (Fig. 127). They were members of benthopelagic fauna and appeared to exert little or no energy to stay at a particular level as they moved over the oozes and the wreckage of the ship. They were free to hover over the sediment and probe it for food, as well as to feed on crustaceans and other organisms that swim over the ocean floor. Most of these fishes (Synaphobranchinae and Simenchelyinae eels, halosaurs, notacanths, macrourids, morids, and ophidiids) contain well developed swim bladders to compensate for the negative buoyancy of their body tissues. Others (skates, squalid sharks, and chimaeras) are without swim bladders but possess other mechanisms to reduce their density. These cartilaginous fish have very large livers filled with a light hydrocarbon (squalene). The low specific gravity of squalene (0.86) and its high concentration in voluminous livers brings sharks close to neutral buoyancy (Denton 1963). Chimaeras and skates also use their enlarged and very mobile pectoral fins to give additional uplift. Slickheads (Alepocephalidae), such as *Alepocephalus agassizi* which were not observed at the site but are common at the depth of the shipwreck, have flimsy skeletons and weak muscles which reduce their specific gravity (Denton and Marshall 1958).

Benthopelagic fishes are more diverse over the continental slopes than in other realms of the ocean. The chimaerids are virtually confined to the slope (Marshall 1971). Most slope dwelling fishes have enlarged eyes with exaggerated lenses and highly sensitive retinas. Halosaurs, macrourids, morids, and ophidiids also show evidence of convergent evolution in the development

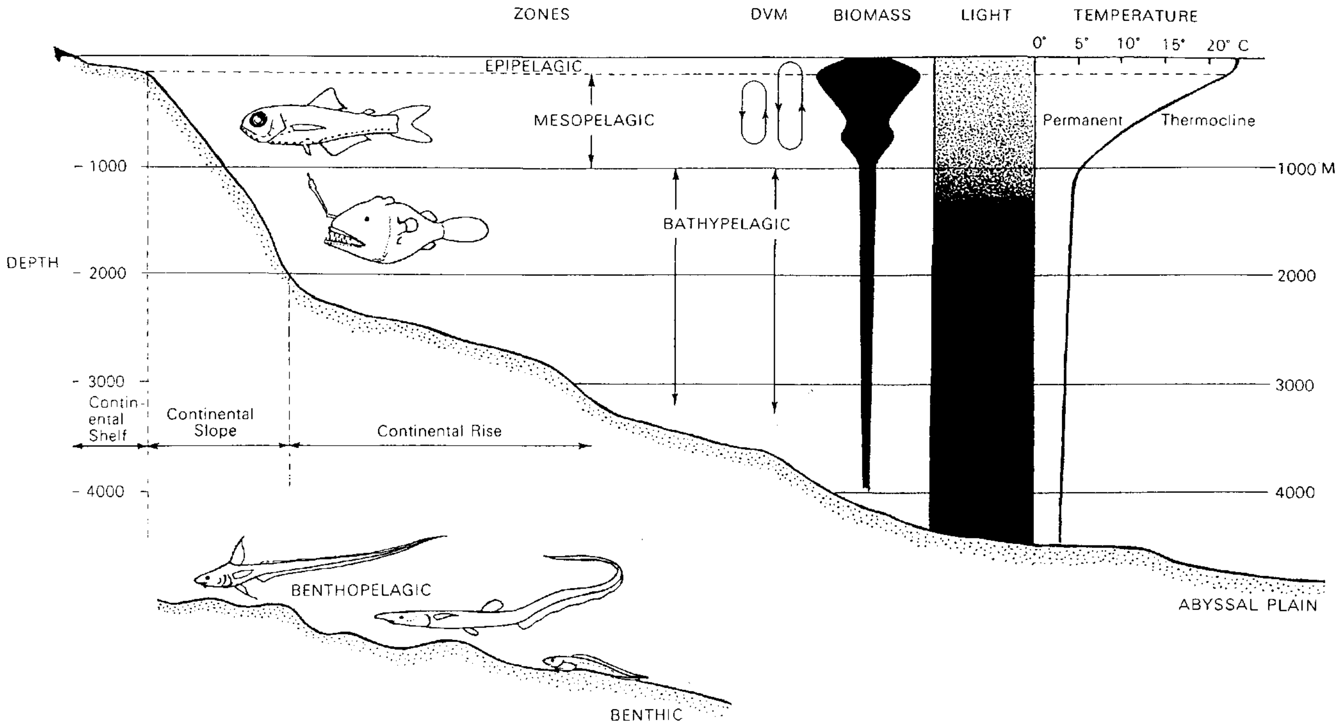


FIGURE 127. Diagram of oceanic features in relation to life zones of deep-ocean fishes: mesopelagic (represented by a lantern fish); bathypelagic (by an anglerfish); benthopelagic (by a grenadier, left and by a halosaur, right); and benthic (by an eelpout). Diurnal vertical migrations (DVM) and biomass of zooplankton are shown near the center and the light regime and the temperature profile are diagrammed at the right. After Marshall (1971).

of enhanced lateral line canals in the head region (beneficial for food locating and communicating in dark surroundings). Studies of macrourids, ophidiids, zoarcids, and cylopterids show that species with populations centered at depths of 200 m to 1,000 m have large eyes, whereas those that live below 1,000 m have small or regressed eyes (Marshall 1971). This circumstance appears to be borne out by the fact that the fish inhabiting the wreck site appeared to be quite unaffected by the powerful lights of *Nemo*. Benthopelagic fishes also converge in respect to their swim bladders. The deeper the habitat, the longer the capillaries (greater surface area) that feed the gas gland of the swim bladder which maintains the efficiency of the gas-conserving and gas-secreting function under greater pressure.

The deep-sea cod *Antimora rostrata*, which reaches 65 cm in length and ranges down to about 3,000 m, has developed a unique feature know as an "ear pod" on the anterior chamber of the swim bladder against the auditory nerve. This apparently hydrophonic arrangement may enhance hearing (Marshall 1979). Male macrourids and ophidiids possess drumming (sonic) muscles on their swim bladders, which may serve a communications function (Marshall 1971).

Other examples of convergent evolution in benthopelagic fishes occur in their form, fin pattern, and jaws. Halosaurs, notacanths, and most macrourids have a long tapering tail, fringed by a long, many rayed anal fin (rattail), and jaws that are set below a projecting snout. The pectoral fins are set laterally and in most there is a short-based dorsal fin. Such a fin pattern generally occurs in association with an underslung jaw. For these fishes, the undulation of the anal fin and tail tends to depress the head, bringing the jaw into a position for securing food from the seafloor. Marshall and Bourne (1964) observed macrourids and halosaurs rooting in deep-sea oozes. These convergent groups of long-tailed fishes comprise well over 50% of the benthopelagic fauna. Some of the ophidiids and morids have slender tails but the anal fin is not differentially enlarged as in other deep-sea groups. Apart from the correlation between the fin pattern and jaw mechanism, elongated tails provide a number of other advantages for survival in the deep sea. Long tails can carry a long-based lateral line, which gives an enhanced means of detecting prey and predators. Also, fishes with many-rayed median fins and a tapering tail are well equipped to undulate slowly and steadily over the ocean floor in search of food or to quickly reverse direction if food is detected behind them. These movements are also possible for the deep-sea eels as demonstrated by synaphobranchids that rapidly reversed direction after swimming into the interior portion of the submersible.

Video images of benthopelagic fishes on the shipwreck site typically showed them heading into currents. Bottom currents there were estimated at about 10 cm/s. This is consistent with currents of 6 to 15 cm/s reported by Hollister and Heezen (1966) for depths below 2,000 m. In facing currents and ranging over the bottom for food, benthopelagic fishes require muscles capable of sustained effort. In groups such as macrourids, ophidiids, and halosaurs, living below 2,000 m, a median strip of red muscle has been retained along the tail myotomes in contrast to bathypelagic fishes (deep-sea species not associated with the bottom) which have lost this feature at similar depths (Marshall 1971).

Benthopelagic deep-sea fishes are thought to have high fecundity as compared to bathypelagic species in the overlying waters. In general, these continental slope-dwelling fish live in a region of richer food sources and therefore are more abundant. Marshall (1965) points out that because most species produce floating eggs, the dominant selection pressures in life-history patterns of slope-dwelling species are related to population maintenances. A significant problem is that the slopes represent relatively narrow strips of deep seafloor and larvae in the surface waters can easily be carried away from the slopes. Macrourids deal with this problem by producing larvae that avoid the warm waters above the thermocline and by quickly passing through early life history stages. Presumably other slope fishes have met the problem of the narrow dropping zone beneath their descending recruits in similar ways. Some benthic species, such as the zoarcids, lay large, heavily yolked eggs which produce large, advanced larvae. Other than these generalizations, little is known of the early life history of benthic deep-sea fishes.

The food habits of benthopelagic fishes off the British Isles, at a depth similar to that of the SS *Central America*, can provide some insight as to the possible food webs at the shipwreck site. Gordon and Duncan (1987) collected 20 species of deep-sea fishes in the Rockall Trough (54 – 57° N, 10 – 12° W) at depths ranging from 2,200 to 2,900 m. At least seven of these same species were observed at the shipwreck site (Table 20). *Coryphaenoides guentheri*, a dominant member of the macrouirid fish community at both locations, was found to be primarily a benthopelagic feeder, consuming mainly copepods, amphipods, mysids, decapods (galatheid crabs and carid shrimps), and isopods. *C. armatus* is a larger and more cosmopolitan species that also feed on a wide variety of crustaceans but fish and cephalopods were the dominant prey items. The halosaur *Halosauropsis macrochir* had a diet of mysids, decapods, amphipods, polychaetes, and cnidarians. The cutthroat eel *Synaphobranchus kaupi*, consumed mainly fish and cephalopods with crustaceans as minor components. Because of the potentially higher diversity of animals on the shipwreck, a more diverse diet can be anticipated for the fish community inhabiting this site.

Several groups of benthic fishes are associated with the floor of the deep sea. In polar and temperate regions these include the rajids (skates), zoarcids (eelpouts), and psychrolutids (deep-sea sculpins). These fishes, which are without swim bladders, spend most of their life resting on the seafloor. These groups show much less evidence of evolutionary convergence than the more pelagic forms. Deep-sea zoarcids, like their relatives in coastal waters, may catch some of their prey by lying in wait and then suddenly seizing it. *Lycodes*, for example, is known to feed on crustaceans, polychaetes, bivalves, echinoderms, and other fishes, all of which were available at the shipwreck site.

MATERIALS SCIENCE

Materials from the shipwreck, including ship parts and passenger items, have been submerged in the deep ocean for over 13 decades. They have thus been exposed to unusual environmental conditions. The degradation effects of pressure, temperature, chemical regimes, and biological processes on iron, wood, and textiles submerged for this period at depths greater than 2 km have received little scientific attention. A better understanding of the processes involved and the results of deep-ocean degradation will permit more accurate prediction of the fate of other cultural objects in the deep ocean.

IRON DEGRADATION

When the SS *Central America* sank in 1857, the wreckage of this wooden-hulled steamer formed a distinct biogeochemical anomaly lying on the relatively featureless Blake Ridge. Wood, iron, copper, lead, gold, and small amounts of silver were carried into a sulfur-rich environment at the water-sediment interface. The engineworks and other machinery accounted for 750 tons of iron, the hull was sheathed with some three tons of copper, and the cargo consisted of precious metals. All the requirements existed for microbiological activity at the shipwreck site, including organic molecules, sources of electrons, solid substrates, and seawater. Every exposed surface of the shipwreck, even the wood timbers, were covered with iron scale or rust features. Dr. Eleanora I. Robbins, geologist and microbiologist, U.S. Geological Survey, and the authors are studying the effects of microbiologically influenced corrosion of the ship's iron. The preliminary results of their investigations are discussed below.

Ballard (1986, 1987) coined the term "rusticles" to describe rust features which covered much of the wreck of the ocean liner RMS *Titanic*. He defined these features as "very fragile reddish-brown stalactites of rust, hanging down as much as several feet, caused by iron-eating bacteria." Aside from color, they resembled long needle-like icicles. The *Titanic* had been resting on the ocean floor for 74 years at a depth of 3,800 m when Ballard made his observations. In 1988 these formations were observed on the wreck of the SS *Central America*, a steamer which had been on the ocean floor for 131 years in 2,200 m of water. Although a wooden vessel, she had hundreds of tons of iron in her machinery. Some of the most dramatic rusticles were observed on the anchor chain, the longest measuring about 30 cm. The *Central America* presented the opportunity to study the rate of rusticle formation because repetitive dives were planned for several years.

Rusticles were prominent features on the ironworks of the *Central America* but not nearly as pervasive as on the *Titanic*. The *Central America* was a wooden ship with engines constructed of iron, similar to today's wrought iron (Greeley et al. 1872), whereas the *Titanic* was a steel-hulled ship (the Bessemer process of steelmaking was not introduced until the later half of the nineteenth century). These two materials, iron and steel, have different corrosion properties in seawater, carbon

TABLE 20

Comparison of abyssal fish species in the eastern and western North Atlantic Ocean at similar depths.

	Rockall Trough NE Atlantic Ocean (Gordon & Duncan 1987)		Blake Ridge NW Atlantic Ocean (present study)
	2,200 m	2,900 m	2,200 m
Family Rajidae (skates)			
Raja bigelowi	•		
Raja jenseni	•		•
Bathyraja pallida	•	•	
Family Squalidae (dogfish sharks)			
Somniosus microcephalus			•
Family Chimaeridae (chimaeras)			
Hydrolagus affinis			•
Family Synaphobranchidae (cutthroat eels)			
Histiobranchus bathybius		•	
Synaphobranchus kaupi	•		•
Simenchelys parasiticus			•
Family Derichthyidae (longneck eels)			
Derichthys serpentinus			•
Family Alepocephalidae (slickheads)			
Alepocephalus agassizi	•		
Bellocia koefoedi		•	
Family Halosauridae (halosaurs)			
Halosauropsis macrochir	•	•	•
Family Notacanthidae (spiny eels)			
Polyacanthonotus challengeri	•		
Family Macrouridae (grenadiers)			
Coryphaenoides armatus	•	•	•
Coryphaenoides brevibarbis	•	•	
Coryphaenoides carapinus	•	•	
Coryphaenoides guentheri	•		•
Coryphaenoides leptolepis		•	•
Coryphaenoides mediterranea	•		
Paracetonurus flagellicauda		•	
Family Moridae (deep-sea cods)			
Antimora rostrata	•	•	•
Laemonema sp. or *Lepidion* sp.			•
Family Phycidae (phycis hakes)			
Urophycis chesteri			•
Family Ophidiidae (cusk eels)			
Barathrodemus manatinus			•
Spectrunculus grandis	•		
Family Bythitidae (brotulas)			
Cataetyx laticeps	•		
Family Zoarcidae (eelpouts)			
Lycodes zoarchus or *L. atlanticus*			•
Lycodes spp.	•		
Family Psychrolutidae (fathead sculpins)			
Cottunculus thompsoni			•

steel being more susceptible to microbiologically influenced corrosion (Moniz 1992), which may account for the longer rusticles on the *Titanic.*

To determine the rate of rusticle growth, a cubical tank, approximately 2 m on a side, was selected for experimentation. The iron tank was one of about 10 on board the *Central America*, presumably used to hold potable water for about 600 passengers and crew. The tank was constructed of iron plates held together with 5-cm wide angle irons which ran the length of each seam. Using one of *Nemo's* manipulators, a side plate was removed, freshly exposing an angle iron to the sea. This work was completed in September 1988 and the tank was photographed for future comparison

(Fig. 128). One year later, in September 1989, *Nemo* was again directed to the same tank. During the intervening period, 14 distinct rusticles had formed along the lower edge of the angle iron. Their lengths were from 4 to 7 cm, with the longest ones being found near the center of the opening (Fig. 129). The rapid rate of growth was surprising considering that the other rusticles on the wreck had 132 years in which to form.

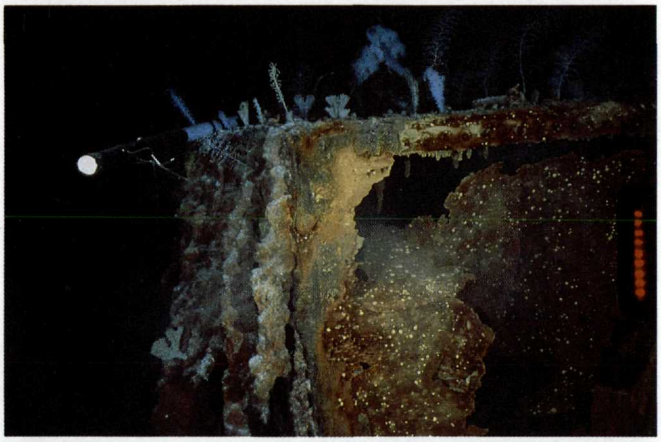


FIGURE 128. Small rusticles hang from the right underside of an angle iron, which is part of a corroding water tank. The ship carried approximately 10 fresh water tanks, about 2 m long on a side. The side panel of this tank was removed in August 1988, exposing the angle iron, its rivets, and rusticles. The right underside was scraped to leave a relatively smooth experimental surface to measure the rate of rusticle growth. Massive iron rust features can be seen flowing down the left side of the tank. The upper surface of the tank has been colonized by gorgonian corals (*Chrysogorgia* new species) and glass sponges (*Farrea* sp., plumed form and *Rhabdodictym* sp., branched form). Animals such as these require hard surfaces for attachment and only occur at this location in the deep ocean because the shipwreck provides such surfaces.

Iron will not rust in dry air, nor in water which is anoxic (free of dissolved oxygen); thus, both oxygen and water are involved in the corrosion process. The presence of electrolytes in the water (i.e., dissolved salts) accelerates corrosion. With typical dissolved oxygen concentrations of 6 ml/l at this depth in the North Atlantic Ocean and a salinity of 35‰ (see Physical Science section), all of the prerequisites for rust formation were met on the shipwreck of the *Central America*. Also, iron in contact with a less active metal (e.g., tin, lead, or copper) corrodes more rapidly than when alone, and less rapidly than when in contact with a more active metal (e.g., zinc). At the time of her sinking, the hull of the *Central America* was completely sheathed below the waterline with copper for wood-borer protection.

Iron corrosion is a complex chemical reaction in which the iron combines with both oxygen and water to form a variety of hydrated iron oxides. Typically, the oxide is a solid that retains the general form of the metal from which it formed but it is porous, bulkier, relatively weak, brittle, and may contain flow structures when formed underwater. In seawater it appears that minute electrochemical cells are set up when iron corrosion takes place (Nebergall et al. 1963). Within these cells the following generalized, reversible oxidation reaction occurs:

$$4\ \text{Fe (iron)} = 4\ Fe^{2+}\ \text{(ferrous iron)} + 8^{e-}\ \text{(electrons)}.$$

Ferrous iron is soluble in seawater and it is in this state that the metal may have some ability to flow under the influence of gravity. In quiet waters, stalactites might be expected to form if it were not for the fact that almost immediately another oxidation reaction takes place:

$$4\ Fe^{2+} = 4\ Fe^{3+}\ \text{(ferric iron)} + 4^{e-}.$$

Ferric iron is insoluble and the rusticle is frozen in place, yielding the solid features observed on the *Central America*. The overall, generalized reaction, involving water and oxygen, thought to be responsible for the formation of rusticles can thus be written as:

$$4Fe + 3O_2 + 6H_2O = 4Fe(OH)_3.$$

However, a mechanism to explain the flow phenomenon is lacking.

In marine environments, many of the conversions in oxidizing iron are mediated by microorganisms. Certain chemosynthetic bacteria can utilize the energy derived from inorganic oxidation of iron to synthesize organic compounds from CO_2 dissolved in seawater. Bacteria belonging to the *Thiobacillus-Ferrobacillus* group possess enzymes that transfer electrons from ferrous iron to oxygen and this transfer results in ferric iron, water, and some free energy being used metabolically by the bacteria (Cole 1988). Other bacteria use the energy derived from oxidizing iron to assimilate, rather than to create, organic material. *Desulfovibrio* is another bacterium associated with iron corrosion that occurs widely in marine environments (Pelczar and Chan 1981). This sulfate-reducing bacterium produces sulfuric acid as a metabolic product which promotes iron corrosion.

FIGURE 129. The same water tank as shown in Fig. 128 one year later (September, 1989) reveals that about 14 rusticles, from 4 to 7 cm in length, have formed on the underside of the scraped angle iron. A manipulator arm of the research submersible *Nemo* can be seen above the tank as it collects a specimen of *Chrysogorgia* new species and a free-swimming feather star, *Caryometra alope*.

ZoBell (1946) was the first investigator to isolate iron-oxidizing bacteria in the marine environment, including the two, sheathed forms *Leptothrix* and *Sphaerotilus* and the globular *Siderocapsa*. These studies and more recent work have shown that iron-oxidizing bacteria are ubiquitous in the sea and thrive where a source of reduced iron is present. Some of the iron oxidizers are aerobes, such as *Leptothrix discophora* but most are heterotrophic, including *Leptothrix ochracea* and *Sphaerotilus natans*. One bacterium, *Gallionella ferruginea,* which puts out holdfasts that intertwine like braids, is known to obtain energy by oxidizing ferrous iron to ferric iron. In marine environments, all of these bacteria can coexist, different ones being more prevalent, depending on chemical and physical conditions.

In 1989 several rusticles were collected by the submersible *Nemo* and examined aboard the R/V *Arctic Discoverer*. Fresh rusticles were somewhat spongy and bright-red in color. When broken, a black interior was revealed and the smell of hydrogen sulfide was noted. This suggested that bacterial sulfate reduction and the formation of sulfide minerals, such as galena (PbS), may take place within the interior environments of the rusticles which are protected from oxygen. When a rusticle was allowed to dry out, it became very hard and difficult to break. Typically, iron oxidation, indicated by the red color when oxygen is present, is commonly thought of as an abiotic process. However, bacteria were suspected of being involved in the rusticle oxidation process because the flexible filaments of certain bacterial colonies could explain the existence of flow features.

FIGURE 130. Iron-oxidizing, rod-shaped bacteria isolated from a rusticle collected at the shipwreck. The bacteria are growing in a bifurcated, filamentous sheath resembling that of *Leptothrix ochracea*. These bacteria precipitate ferrihydrite, an amorphous, hydrated iron oxide mineral. The bacterial sheaths are coated with iron oxides. Photomicrograph courtesy of Dr. Eleanora I. Robbins.

Microscopic examination of rusticles from the *Central America* at 400X and 1,000X revealed an abundance of microbes. A number of forms were found, including many rather ordinary and colorless rods, spheres, and filaments while others had more distinctive morphologies, such as *Hyphomicrobium* which resembled a cotton swab—two cells at either end with a hypha between. The bulk of the bacteria, however, produced bright-red sheaths typical of iron oxidizers. Dr. Robbins found that the most distinctive of these bacteria had chains of internal rods, 0.5 μm wide, in bifurcated, curled carbohydrate sheaths. The sheaths were coated with iron oxides (Fig. 130) which in some cases increased their width to 9 μm, representing a significant amount of iron oxidation.

On close inspection, it was evident that the living cells of the dominant bacteria associated with deep-sea rust features were enclosed in a non-living sheath or tubule. The sheaths were impregnated with insoluble metal compounds, particularly ferric hydroxides, precipitated around the cell as products of their metabolic activity. The sheath was commonly extended around numerous individual cells, aligned end to end, giving the impression of filaments of growth. Photomicrographs of such bacteria from the *Central America* revealed cells emerging from a new sequence of sheath-formation (Fig. 131). Innumerable empty sheaths appeared to have accumulated on the wreck, forming reddish flocculent masses and coating the iron, wood, coal, and even some of the gold with a reddish-brown deposit. Dr. Robbins has tentatively identified the sheath-formers as the iron-oxidizing bacteria *Leptothrix* and *Siderocapsa*. Formal identification will require separating isolates, analyzing biochemical traits, and performing DNA-DNA hybridization experiments on fresh material.

In October 1991, Dr. Robbins performed an experiment at the U.S. Geological Survey laboratories in Reston, VA, to determine if bacteria were involved in the

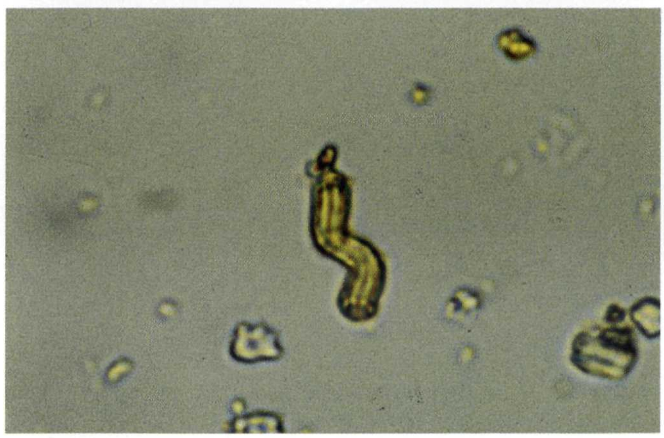


FIGURE 131. Iron-oxidizing, rod-shaped bacteria isolated from a rusticle collected at the shipwreck. The bacterium in the center appears to emerging from its sheath, the first step in extending the length of the sheath. Photomicrograph courtesy of Dr. Eleanora I. Robbins.

formation of rusticles on the SS *Central America* shipwreck. Six vials were filled with well oxygenated, sterilized seawater. A sterilized piece of ferrous iron (about 10 g of pig iron) was placed in each vial. To simulate the iron of a nineteenth-century steamer, pig iron was chipped from an ingot that had been recovered from a Civil War period blast furnace in Virginia. One gram of fresh rusticle material recovered from the *Central America* was added to three of the vials and none was added to the set of control vials. All vials were immediately sealed. The iron proceeded to rust immediately in both sets of vials. The water in the experimental vials inoculated with rusticles turned red in 14 days and the inner walls of the vials became opaque from colonization by iron-oxidizers on these fresh surfaces. In the control vials, no colonization was noted on the vial walls. In the inoculated vials, films having an oily sheen appeared on the surface of the water. Two years later (October 1993), the inner walls of the rusticle-containing vials still exhibited reddish-brown deposits. Examination of these colonies with a light microscope (1,000X, oil immersion) revealed bacteria that resembled in behavior and structure *Leptothrix discophora*, including the presence of 3-μm spheres that appeared to be holdfasts but differed somewhat from the typical form of this species by exhibiting bifurcation.

To verify the type of bacterial activity at the shipwreck site, a collection device was fashioned that would hold 14 microscope slides in a caddy so that each surface was freely exposed to seawater. The device was carried to the ocean floor inside *Nemo*'s storage compartment and placed within the wreckage. After being deployed for one month, all of the slides were red-colored from the iron oxidizers that colonized them. Dr. Robbins also found numerous colonies of rather nondescript, colorless bacteria. Dr. Robert Jonas, professor of microbiology, George Mason University, confirmed that the colonizers were bacteria by coating the slides with a DNA stain (acridine orange) and viewing them with an epifluoresence microscope. Again, the bacteria exhibited the characteristics of *Leptothrix*.

Stoffyn-Egli and Buckley (1992, 1993) studied the mineralogy and microbiology of rusticles recovered from the *Titanic* in July 1991. They concluded that bacterial activity in rusticles caused the precipitation of an outer shell of lepidocrocite, γ-FeO(OH). Inside the rusticle, the presence of euhedral goethite crystals, α-Fe^{+3}O(OH), indicated that dissolved iron concentrations must exceed the solubility product of this mineral. They attributed the formation of rusticles to sulfate-reducing bacteria in spite of the relatively well-oxygenated conditions in the marine environment surrounding the *Titanic*. To account for this apparent paradox, they speculated that reducing conditions occur on a small scale within rust flakes, resulting in the precipitation of stable reduced minerals, such as siderite ($FeCO_3$) and galena (PbS). They explained the coexistence of minerals of different redox potentials as probably the result of slow reaction kinetics.

Research on SS *Central America* materials, however, suggested an alternative explanation for the formation of rusticles; rather than reducing bacteria as postulated for the *Titanic*, iron oxidizers appear as the dominant forms responsible for rusticle formation in the deep ocean. To test this speculation, Samuel O. Raymond, ocean engineer and founder of Benthos, Inc. (a participant in the 1991 *Titanic* expedition) provided the authors and Dr. Robbins with a rusticle obtained from the stern of the *Titanic* in July 1991. In March 1992, the *Titanic* rusticle was subjected to the same experimentation as the *Central America* rusticle. The test results were identical, with the inoculated vial producing colonies of iron-oxidizers with characteristics similar to those of *Leptothrix*.

In the 13 decades since the SS *Central America* sank, the ironworks have undergone significant degradation. When first viewed in 1988, iron oxides coated virtually all exposed surfaces of the shipwreck and patches of the surrounding sediment ooze. This corrosion appeared to be strongly influenced by microbial activity. Flow structures, such as rusticles, are believed to be iron-oxide edifices composed of a community of various iron-oxidizing bacteria and their metabolic by-products. The process of colonizing surfaces and oxidizing iron probably gave the rusticles their distinctive rust color, and the plasticity imparted by the bacterial sheaths may account for the flowage needed to create their stalactite-like form. Thus, the formation of rusticles appears to have several requirements. These include: 1) an iron substrate, 2) relatively quiet, well-oxygenated, saline water, and 3) appropriate microbial activity. The requirement, if any, of deep-sea pressures has not yet been determined but seems unlikely, based on laboratory results at atmospheric pressure.

COPPER-ALLOY DEGRADATION

Copper-alloy materials (e.g., brass and bronze) observed on the shipwreck site included the ship's bells, hull sheathing, porthole fittings (Fig. 132), trunk latches, luggage tags, oil lamps, navigation tools, and a padlock (Fig. 133). In September 1988, the ship's bell was recovered from the site (Artifact No. 8004). The 125-kg bell

FIGURE 132. *Nemo's* manipulator is used to explore a porthole (Artifact No. 31034) on the shipwreck. An artifact collection tray lies to the left of the porthole. A sea anemone (*Paractinostola* new species?) is attached to collapsed hull timbers next to the porthole.

FIGURE 133. A brass padlock is recovered with a suction picker operated from *Nemo*'s manipulator (Artifact No. 29026). A soap dish has already been placed in the collection tray (Artifact No. 29019).

bore the raised inscription on a band near the top, "*MORGAN IRON WORKS - NEW YORK - 1853*." The bell was one solid piece (Fig. 39); the clapper was missing. The composition of the bell is thought to be an alloy of copper and tin at a 5:1 ratio with minor amounts of zinc and lead (Coleman 1928). While under water, the bell was partially buried (Fig. 38), thus placing the bell in three environments: 1) oxygen-rich seawater, 2) oxidized sediment (<5 cm deep), and 3) reduced sediment (>5 cm deep). After retrieval, the bell was held in several additional environments, including: 1) air, 2) argon atmosphere, 3) tap water, and 4) deionized water. The combination of these environments has resulted in a variety of corrosion products on the bell's surface. Holding the bell in deoxygenated, deionized water at 4° C appears to have stabilized the alloy and arrested further degradation. Another bell was found at the shipwreck site that was simpler in design and smaller (1.3 kg). It was most likely used as a signal bell (Artifact No. 29023). The small bell was stored in air and like the larger bell, it exhibited multiple regions of corrosion products on its surface.

Several bundles of brass luggage tags with leather straps (approximately 400 individual tags) were recovered from the site (e.g., Artifact No. 34040). Presumably, these were used on the Atlantic and Pacific legs of the trip as well as on the Panama Railroad. Two luggage tags, without leather straps, were selected for conservation treatment as described by MacLeod and North (1979) and MacLeod (1987) for removing "bronze disease," a common name for copper hydroxy chlorides which develop on copper alloys (Daniels 1981). Before treatment, the tags were chemically analyzed using SEM microprobe analysis and found to be predominantly copper and zinc with trace amounts of niobium and molybdenum. Both of the tags showed evidence of bronze disease and were unreadable. Before treatment, loose corrosion products were removed by wiping. The tags were then placed in an alkaline dithionite solution. The corrosion products reacted almost immediately upon entry in the solution and a brown precipitate was noted as it came off the tags. Within 2 hr, the solution was filled with a brown precipitate and within 5.5 hr, inscriptions (e.g., "SAN F$^{\underline{o}}$ TO N.Y. /806/VIA/PANAMA") on the cleaned surfaces were readable. At 11.5 hr, the tags were removed to a fresh sodium dithionite solution but no further reaction was observed. Twenty-four hours after the beginning of treatment, the tags were removed from the solution and placed in deionized water for three days. After air drying, excess precipitate was brushed off with a camel-hair brush. The treatment was successful in removing detrimental corrosion products from the luggage tags. After the treatment, the tags appeared rust-brown in color. A white precipitate was noted on one of the tags, which possibly was zinc that leached out of the tag during the conservation process. A similar phenomenon has been reported in previous studies (MacLeod 1987). Monitoring of the tags showed no evidence of reoccurring bronze disease 18 months after the treatment.

A gimbal set recovered from the SS *Central America* site also showed signs of bronze disease (Fig. 134). The set may have been used to stabilize the ship's compass (or possibly a lamp). The method employed to remove corrosion products from the luggage tags was also used to treat the components of a gimbal set: concentric ring (Artifact No. 33676), peg (Artifact No. 33882), and square bracket (Artifact No. 33883). Like the luggage tags, the pieces were placed in repeated baths of sodium dithionite solution for 24 hours. After treatment, the pieces were placed in deionized water until the water reached a neutral pH. The artifacts became brown in color once the corrosion products were removed (Fig. 135). Two years after the treatment was completed, these artifacts showed no signs of reoccurring bronze disease.

WOOD DEGRADATION

The ability to penetrate and live within firm substrate, such as rock, coral, shell, or wood, has evolved in several families of bivalve molluscs (Barnes 1987). Wood-boring bivalves belong to two principal families: Teredinidae (shipworms) and Pholadidae (deep-sea borers). The pholadids appear to be bottom-obligate forms which infest wood that has found its way to the floor of the deep

FIGURE 134. Concentric ring of a gimbel set recovered from the shipwreck (Artifact No. 33676). Photograph taken before conservation treatment was begun.

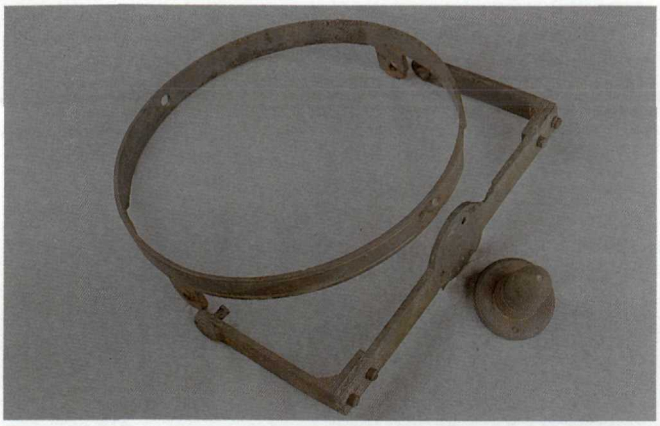


FIGURE 135. A gimbel set recovered from the shipwreck (Artifact No. 33676 – concentric ring; No. 33882 – peg; No. 33883 – square bracket). Photograph taken after conservation treatment was completed.

ocean, while the teredinids are more adapted for shallow-water environments. The common shipworms of the family Teredinidae are serious pests of piers, pilings, ships, and other wooden structures placed in the sea by man. Noteworthy in this family are the genera *Teredo* and *Psiloteredo* whose infestations, along with the boring isopod *Limnoria*, cause millions of dollars worth of damage each year (Clapp and Kenk 1963). Members of this family only thrive near the ocean's surface and do not persist to the depths of the continental slope where the wreck of the SS *Central America* was found. Thus, at a depth of 2,200 m, only members of the Pholadidae family were believed to be present and responsible for much of the destruction of the ship's wood.

All boring bivalves begin excavation following the settlement of the larva and slowly enlarge and deepen the burrow with growth. They are, however, permanently locked within their burrows and only the siphons project to the small surface opening. If an adult boring bivalve is placed on a fresh surface, it cannot excavate a new chamber; only the larva has the ability to initiate burrows. The body of the typical wood-boring mollusc at the site was greatly elongated and cylindrical. The reduced shell consisted of two small valves with serrated edges on its anterior end (Fig. 136). Cutting of the wood was effected by opening and closing the valves and rotating them from side to side while a small foot anchored the body to the side of the burrow. The mantle, enclosing the greater part of the body behind the valves, produced a calcareous lining or tube within the tunnel (Fig. 136). These tubes were very much in evidence in the timbers of the *Central America* (Fig. 137) and littered the bottom where the wood had completely disintegrated. The long, delicate siphons open at the surface of the wood; when the siphons are retracted, the burrow entrance is plugged by calcareous pallets for protection against predators, especially galatheid crabs. Most of the tubes observed at the shipwreck site appeared to be empty.

Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University, conducted a series of experiments on deep-ocean wood borers which provided a model for the present study. She set wood panels on the ocean floor (1,830 m deep) near Woods Hole, MA, in the early 1970s using the research submersible *Alvin* (Turner 1973, Culliney and Turner 1976). In about 15 weeks, the wood was completely riddled by pholadid species such as *Xylophaga abyssorum* and *Xyloredo nooi*. Dr. Turner inspected wood and tubes recovered from the SS *Central America* in 1989 to 1991 and concluded that the burrows were made by pholadids, most likely *Xyloredo* spp.

Discounting the shells of the pelagic pteropods in the sediment ooze, the most abundant evidence of molluscs in the vicinity of the shipwreck was many thousands of wood-borer tubes (Figs. 65, 85, 138) which ranged in length from a few centimeters to over 40 cm. The tubes resembled those of shallow-water Teredinidae but the valves lacked the distinctive apophysis of this group (Turner 1966) and had other features that suggested to Dr. Turner that they may represent two new species of deep-water pholadids, probably in the genus *Xyloredo*.

Video images showed that the hull timbers, as well as interior support members such as oak knees, had been riddled by boring bivalves. This indicated that

FIGURE 136. Several valves (upper right) and variously shaped tubes of wood-boring bivalves recovered from the shipwreck site. These deep-ocean wood borers (family Pholadidae) apparently invaded the ship's timbers and caused much of the vessel's disintegration. The tubes are larger than previously described xylophagains and may represent two new species in the genus *Xyloredo*. The white tab at the bottom of the photograph is 5 cm long. Photograph courtesy of Dr. Ruth D. Turner.

FIGURE 137. A collapsed hanging knee of the SS *Central America* lying on pteropod ooze. The calcareous tubes of pholadid bivalves can readily be seen. The infestation of this member, which was not exposed to seawater while the ship was afloat, could only have taken place on the ocean floor once the ship had sunk.

the infestation had to occur on the ocean floor after the ship had sunk. Examination of numerous samples of wood recovered from the wreck failed to yield any soft parts of these animals. In September 1990, 20 test panels of wood (10 hard pine and 10 oak to simulate the materials of the ship) were set on the ocean floor at the shipwreck site (Fig. 76). In August 1991, one oak and one

FIGURE 138. The seabed surrounding the shipwreck is littered with the calcareous tubes of wood-boring bivalves. These concentrations indicate that wooden portions of the ship may have completely disintegrated.

pine panel were recovered after 357 days of submergence on the wreck site. Preliminary examination of the panels indicated no evidence of borers in the oak panel but several small openings were found near the top of the pine panel. When the panel was cut into segments, it was noted that the small pin holes quickly opened into bore holes up to 25 mm long and 7 mm in diameter. Dr. Turner found that they were lined with calcareous tubes and contained valves typical of the pholadid bivalve, *Xyloredo* (Fig. 139). A longer incubation time was anticipated to yield larger specimens for more detailed study. To pursue this idea, the authors and Dr. Turner placed nine additional panels on the ocean floor in August 1991. This deployment consisted of soft pine to induce more rapid borer growth and the panels were encased in fine-mesh bags to capture other animals that settled on the wood and grew too large to escape through the mesh. A similar technique, employed by Turner (1977) and by Williams and Turner (1986), proved successful in obtaining specimens from depths up to 4,000 m in the North Atlantic Ocean.

Shipworms and other wood borers appear to use the excavated sawdust for food. Their stomach is provided with a caecum for storage of this material and a gland that is specialized for digesting cellulose. Symbiotic bacteria, housed in a chamber that opens into the esophagus,

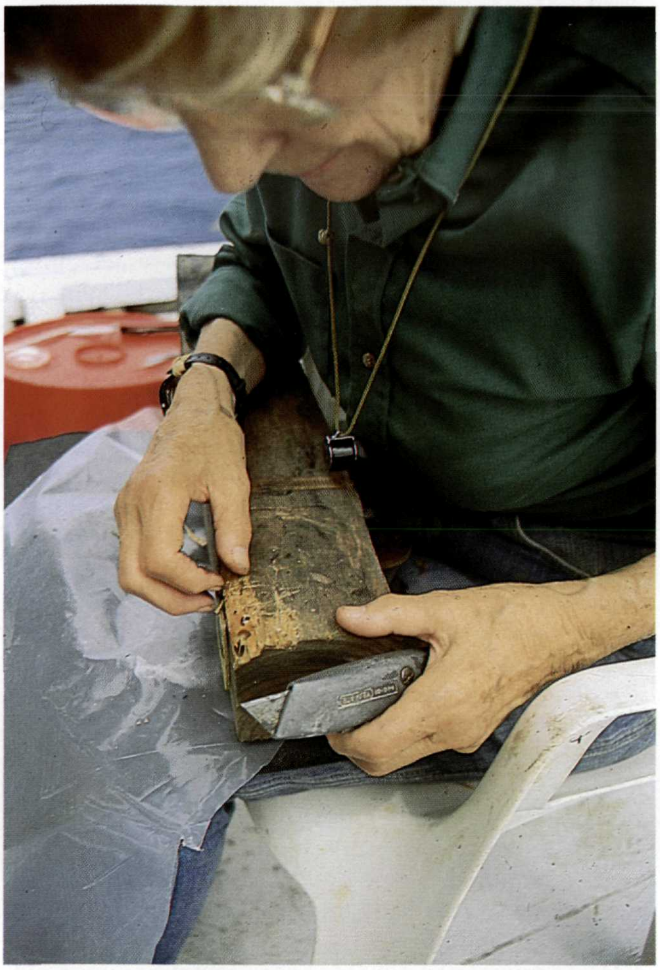


FIGURE 139. A wood panel is examined by Dr. Ruth D. Turner that has been submerged at the shipwreck site for nearly one year (September, 1990 to August, 1991). The opening and small tube of a pholadid wood-borer can be seen where the panel has been cut open.

also provides cellulose digestion as well as nitrogen fixation which compensates for the low-protein diet of the wood (Morton 1978). Almost certainly, these animals depend partly or largely on bacteria for their nutrition. Plankton has traditionally been regarded as the principal food of *Teredo*; however, ZoBell (1946) reported that wood loses about 80% of its cellulose during passage through the digestive tract of this wood borer. The gut of engorged *Teredo*, as well as its burrows, were found to contain large numbers of cellulose-digesting bacteria. Conceivably, commensal bacteria convert wood cellulose and lignin into products which are more readily assimilated by the wood borers. However, the quantity of bacteria present at any one time in the burrow or gut of the *Teredo* was not sufficient to meet the entire food requirement of this animal.

Other studies suggest that cellulose- and lignin-decomposing microorganisms may condition the wood for initial attack by wood borers (Barnes 1987). Extensive degradation of wooden structures by fungi in the sea has been reported by Barghoorn (1942). He observed a conspicuous softening in the outer parts of pilings and submerged wood and proposed that the activity of such organisms may help explain why wood becomes increasingly more susceptible to attack by wood borers as its period of immersion increases. ZoBell (1946) concluded that, given sufficiently extended time, either bacteria or fungi could independently effect the complete deterioration of submerged wooden structures but the rate would be far slower than the rapid destruction of wood by *Teredo* or *Limnoria*. Although highly degraded, the wooden timbers of the *Central America* were still very much in evidence after more than 130 years of being submerged on this deep-ocean floor. This suggested that, compared with shallower environments, both microbial and wood-borer activity had been greatly slowed, presumably by environmental constraints (e.g., temperature, pressure, and isolation) or possibly by lost nutritional value in the wood over time.

TEXTILE DEGRADATION

Textiles are rarely recovered after long periods of submergence in the marine environment; thus, little is known about the degradation process, the physicochemical structure of the degraded fabrics, or appropriate methods of conservation. As a result most conservation efforts have been experimental; these efforts have met with varying degrees of success and failure. Since the opportunity existed to work with a large number of waterlogged textiles by virtue of the passenger trunks recovered from the SS *Central America*, Dr. Kathryn A. Jakes, Department of Textiles and Clothing, The Ohio State University, was able to develop and execute a research plan that has contributed materially to the knowledge of waterlogged historic textiles and their conservation.

The recovery of the Easton trunk in 1990 (see Underwater Archaeology section) yielded fabrics with cotton, flax, wool, and silk fibers that had been packed rather tightly in a sealed trunk. Representing long term storage in a deep-marine environment, the textiles were ideal objects for degradation study. The fabrics exhibited extensive patchy black stains and smaller areas with reddish-brown and greenish-black stains (Fig. 140). Most individual fibers were identifiable from their morphological characteristics using light microscopic techniques but some required chemical determinations by infrared microspectroscopy (Jakes and Wang 1993). Some loss of surface scale structure in wool fiber was attributed to mechanical degradation during use but bulges, cracks, and fibrillation of fibers appeared to be related to degradation in the deep-ocean environment. The stains on the fibers were composed primarily of iron, sulfur, and copper deposits, suggesting the action of sulfide producing anaerobic bacteria within the trunk. Differential staining within the trunk and from one fiber to another on the same fabric indicated that mechanisms had operated to constrict the deposition process.

The quantity of waterlogged textiles available allowed Dr. Jakes to also use some for experimentation. The goal of this work was to find an ideal drying method that would preserve the fiber and fabric structure while at the same time allowing the textile to be stored in the ambient conditions of a typical museum. To determine the best drying method, samples of wet trunk lining were

FIGURE 140. A rose-colored, print dressing robe recovered from the Easton trunk (Artifact No. 29057). Note patches of black and reddish-brown staining.

treated in five ways: 1) air drying, 2) ethanol dehydration, 3) critical point drying, 4) vacuum freeze drying, and 5) freeze and slow drying. The trunk lining used in these tests was a coarse, plain-woven linen fabric with a yarn count of 112 x 130 strands/cm.

Examination of scanning electron micrographs of the test specimens for each treatment suggested that vacuum freeze drying was more disruptive than air drying, ethanol dehydration, critical-point drying, or slow drying in a frozen state. Although the ethanol and critical-point methods gave satisfactory visual results, they were less desirable because of possible chemical changes to the fiber from the solvents involved. Microbial damage was evident in the air-dried lining. Thus, slow drying in a freezer at -28° C proved to be a low-cost, effective way to salvage waterlogged textiles with minimal damage to fiber structure (Jakes and Mitchell 1992).

Additionally, x-ray microanalysis was performed by Foreman and Jakes (1993a, b) on textile samples taken from the lining of the Easton trunk: two handkerchiefs, a pair of long underwear, a shirt collar, and two shirts. Another group of test fabrics (modern linen) that had been deployed at the shipwreck site for three months was similarly analyzed. These samples were tightly packed in polyethylene jars constructed with tubing vents at each end to allow ocean water to enter during the test period (Fig. 76). Before retrieval, pinch clamps on the tubes were closed to seal the water inside the immersion jars.

X-ray diffractometric equipment was used to study and compare textile fiber crystallographic characteristics of the trunk and the immersion jar samples. This technique was selected based on the work of Ward (1950) who showed that crystal size and percent crystallinity are linked to the physical performance of fabrics and are related to physical property changes as a consequence of degradation of cellulosic polymers. For historic textiles, Foreman and Jakes (1993a, b) found that: 1) the microcrystallite size of the textiles increased, 2) the percent crystalline component decreased, and 3) the unit cell dimensions remained constant. For modern linens immersed for three months, they found that: 1) the crystallite sizes did not increase, 2) the percent crystalline component decreased, and 3) the unit cell dimensions also remained constant. Thus, long periods of immersion in seawater appear to be needed to cause alteration in crystallite size, particularly the growth of microcrystallites within degrading fibers.

In conjunction with Dr. Jakes research, microbiological analyses were performed by Dr. Cynthia Miller, Department of Microbiology, The Ohio State University, on water samples taken from the Dement trunk (see Underwater Archaeology section) and from the immersion jars. Samples from the trunk (0.1 ml) were injected into 5.0 ml tubes of marine broth and nutrient broth and incubated at 4° C with aeration for one week, then 0.1 ml subsamples were plated on marine broth agar and nutrient agar. In all samples, approximately 50 to 60 colonies appeared on the plates, exhibiting at least five distinct colony types. None of the organisms isolated grew at room temperature and no fungi were isolated from the trunk samples. All of the colonies consisted of short, Gram-negative rods. The samples from the immersion jars were treated in a similar manner but showed less colonization and less diversity of colony types, usually only two or three. All trunk and immersion jar samples yielded microbial activity after enrichment with media and all of the microbes appeared to be obligate psychrophiles. Although the extent to which microbial activity facilitates degradation has not been determined, these analyses have demonstrated the existence of microbial activity in the proximity of degraded textiles in the deep ocean.

Working under Dr. Jakes direction, Wenwei Wang further analyzed the morphological characteristics and physicochemical properties of flax fiber/linen fabric exposed to the deep-ocean environment for three months in immersion jars at the shipwreck site. Some of the immersion jars were filled with copper or iron plates. When compared to control samples, the fibers in the test jars exhibited changes including bulges, cracks, and fibrillation. The bulges appeared to be the result of bacterial growth under the surface of the fiber, while the cracks and fibrillation were attributed to swelling stress. Some "eaten away" areas on the fabrics were also probably the result of bacterial deterioration. Fibers in the jars with no metals displayed more bulges than those with copper or iron, suggesting that these metals may have inhibited bacterial growth. Measurement of other physicochemical features, such as yarn size, color, and crystallinity showed that fibers in the immersion jars had undergone only small changes during the test period. Most notable were color changes; fabrics became darker after submergence, those treated in association with iron became redder and those with copper became greener. The lack of significant alterations in the test fabrics was attributed to slow degradation processes in the dark, cold environment and their relatively short period of immersion at the shipwreck site (Wang 1992, Wang and Jakes 1994). Additional textiles remain at the site for future retrieval and study.

UNDERWATER ARCHAEOLOGY

Underwater or maritime archaeology involves the scientific study, through surviving material evidence, of all aspects of seafaring, including vessels and their equipment, cargoes, passengers, and crew, especially artifacts reflecting a maritime life style (Muckelroy 1978). As with all phases of archaeology, underwater archaeology is problem oriented and studies are conducted with questions outstanding in the discipline kept as a continuing perspective. A wooden steamship lost on the high seas is likely to reach the seabed reasonably intact, carried to the bottom by the weight of iron machinery, coal, or other contents. Thus, such ships are likely to be of greater archaeological significance than a wooden vessel that breaks apart on striking a shoal, spilling its cargo, and scattering its constituent parts. Records kept by Lloyds of London show that about 20% of all vessel sinkings have occurred well away from the coast (Bascom 1976). As pointed out by Muckelroy (1978), only when disaster strikes during a voyage and everything—ship, cargo, and shipboard community—is deposited on the seabed, is there any chance of a permanent material record which is archaeologically recoverable. Otherwise, a ship undertaking a voyage leaves no imprint on the archaeological record, and if all goes as intended, the evidence is dispersed at the end of the voyage, when the cargo is sold, the passengers disembark, and the ship is taken on a new enterprise.

Discovery of the shipwreck of the SS *Central America* presented several important research questions within the realm of underwater archaeology, including: 1) seaworthiness of the vessel prior to the sinking, 2) transformation processes acting on a shipwreck in the deep ocean, 3) life styles of the eastward-bound passengers, 4) shipboard environment on a mid-nineteenth century Panama-Route steamer, and 5) numismatic practices of 1857. Projects were designed to investigate these questions at the site using special observational and collection techniques afforded by the research submersible *Nemo*.

The wrecking of the SS *Central America* created a unique time capsule for its era. The site contained artifacts which reflected life on board one of the great ocean-going steamships of her time. The artifacts also provided insight about the everyday life styles of the voyagers. Many had migrated to California to make their fortunes from the gold fields and were on their way back East. *Nemo*'s cameras were used to take video and still photographs from various angles to document each object, to establish relative positions of objects within the shipwreck, and to select areas in which to excavate (Figs. 141, 142). Simultaneously, on board the *Arctic Discoverer*, artifacts were electronically logged. Once this was done, *Nemo*'s manipulators were used to grasp artifacts and place them in padded trays (Figs. 132, 133). The trays were then placed inside *Nemo*'s storage compartment to protect the artifacts on their way up to the ocean surface. Once *Nemo* was on deck, the trays were removed (Figs. 143, 144, 145) and taken to a shipboard laboratory where the artifacts were stabilized, cataloged, and stored for further conservation and study at shore-based laboratories. A monitoring program was established to routinely assess the condition of artifacts stored in the laboratories and conservation treatment to initiate in cases where long-term preservation was jeopardized by the environment.

Nearly 800 cultural artifacts or artifact groupings were recovered from the SS *Central America* site and classified during the period 1988 to 1995. The nomenclature system presented by Blackaby and Greeno (1988) for man-made objects was used, with minor modifications, to catalog the artifacts. Based on this hierarchical system, artifacts from the *Central America* were placed in 11 different use categories and further subdivided into 30 classes and 163 types of objects. An annotated listing of the artifacts recovered from the shipwreck site was made (Appendix C).

SEAWORTHINESS OF THE VESSEL

Numerous accusations of the SS *Central America* being "rotten and unseaworthy" prior to the sinking are documented by Delgado (1983). The *San Francisco Daily Alta California* (22 October 1857) even suggested that the ship's name had been changed in 1857 to delude the public into thinking the old "rotten" *George Law* had been rebuilt, or that the *Central America* was a new ship. The United States Mail Steamship Company countered with statements that: "the *Central America* was a staunch boat, well-built, and in good condition" and that: "recent inspections of the ship had proved this, and the loss was an Act of God" (Delgado 1983). The Panama correspondent for the *San Francisco Daily Evening Bulletin* (18 November 1857) reported that twice in 1857 the ship had gone aground, loosing much of the copper sheathing and when the copper was replaced that summer, it was: "applied directly over a healthy colony of shipworms, who were already eating their way into the heart of the ship."

The question of the ship's seaworthiness was unanswerable at the time of the sinking and the controversy raged on for months, particularly in California. The contention that borers had invaded the hull of the *Central*

FIGURE 141. The once proud steamship now lies in ruin on the deep-ocean floor, a victim of thirteen decades of decay. The outline of the ship is still revealed by the close-spaced hanging knees which once supported the decks but now stand like sentinels guarding the ship's remains. Wash basins and a water pitcher from the ship's cabins lie partially buried in the soft sediment ooze near one of the hanging knees (Artifact Nos. 29001, 29002 – wash basins; No. 29000 – pitcher). A cross-shaped medal can be seen at the right on the lower portion of the knee (Artifact No. 33691; see Fig. 173).

America was plausible because shipworm damage to wooden ships sailing the Panama Route has been well documented (Clapp and Kenk 1963). As discussed in the sections of this paper on Marine Biology and Materials Science, shipworms are highly specialized bivalves adapted for boring into wood (family Teredinidae). They are most prevalent in tropical and subtropical waters, often associated with mangrove roots and timbers swept into the sea by rivers (Barnes 1987). Shipworms can only invade new wood during a short larval period (normally 1 to 2 days) when they are free swimming (Turner 1966). The initial entrance hole is small and is only slightly enlarged as the animal grows. Consequently, the interior damage goes undetected until the structure of the wood is nearly destroyed, causing the timber to disintegrate. As they grow, shipworms produce a calcareous lining for their burrows which often survive as hollow tubes long after the wood has disintegrated and the animals have died. Turner (1966) referred to shipworms as: "termites of the sea."

Direct observation of the shipwreck and examination of the timbers recovered from the site provided a way to evaluate the seaworthiness of the vessel before the sinking. Such investigations were made by the authors working in conjunction with Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University. Wood-borer tubes were abundant on the shipwreck site, both in timbers and littering the seabed where wood had completely disintegrated. An obvious immediate notion was that the hull must have been heavily invaded with shipworms to produce the large number of tubes. The tubes superficially resembled those of the shallow-water Teredinidae that would be expected along the route of the *Central America*. However, when the associated cutting valves were inspected, it was noted that they lacked a distinctive apophysis which is characteristic of teredinid shipworms (Turner 1966). The tubes turned out to belong to a deep-water family, Pholadidae. This group has no apophysis but it was also not known to produce large tubes (see Materials Science section). Some of the tubes were in the 30 to 40 cm range while another group was generally less than 15 cm long. Based on her observations, Dr. Turner concluded that most of the wood destruction was caused by two new species of pholadids, probably in the genus *Xyloredo*.

Some evidence of shipworm (teredinid) borings was found (most likely *Psiloteredo healdi*), which indicated that the hull had been infested to some degree before the sinking. However, this shallow-water Caribbean

FIGURE 142. An assortment of beverage bottles (e.g., Artifact No. 8002), probably once containing beer and wine, rests on the sediment ooze in the debris field adjacent to the shipwreck. To the left of the bottles are a number of ambrotype photographic plates (e.g., Artifact No. 33822; see Fig. 157).

species could not survive at the depth of the shipwreck and could not have caused the structural damage in evidence at the site. In any event, the minor damage attributable to teredinids was not sufficient to adversely affect the ship's seaworthiness.

Another factor in support of the conclusion that deep-water borers rather than shallow-water shipworms were the primary invaders was the location of the holes. Many of the infested timbers were situated well above the ship's waterline. Video images of the interior support members, such as oak knees, indicated that they were riddled by deep-ocean, wood-boring bivalves (Fig. 137). This could only have happened after the ship was submerged in deep water.

FIGURE 143. Collection trays being retrieved from *Nemo*'s storage compartment. The artifacts in the foreground are cream and water pitchers from the shipwreck (Artifact Nos. 29008, 29004, 29000, left to right).

FIGURE 144. Inspecting an ironstone water pitcher recovered by the submersible at the shipwreck site (Artifact No. 29000; see Figs. 143, 169).

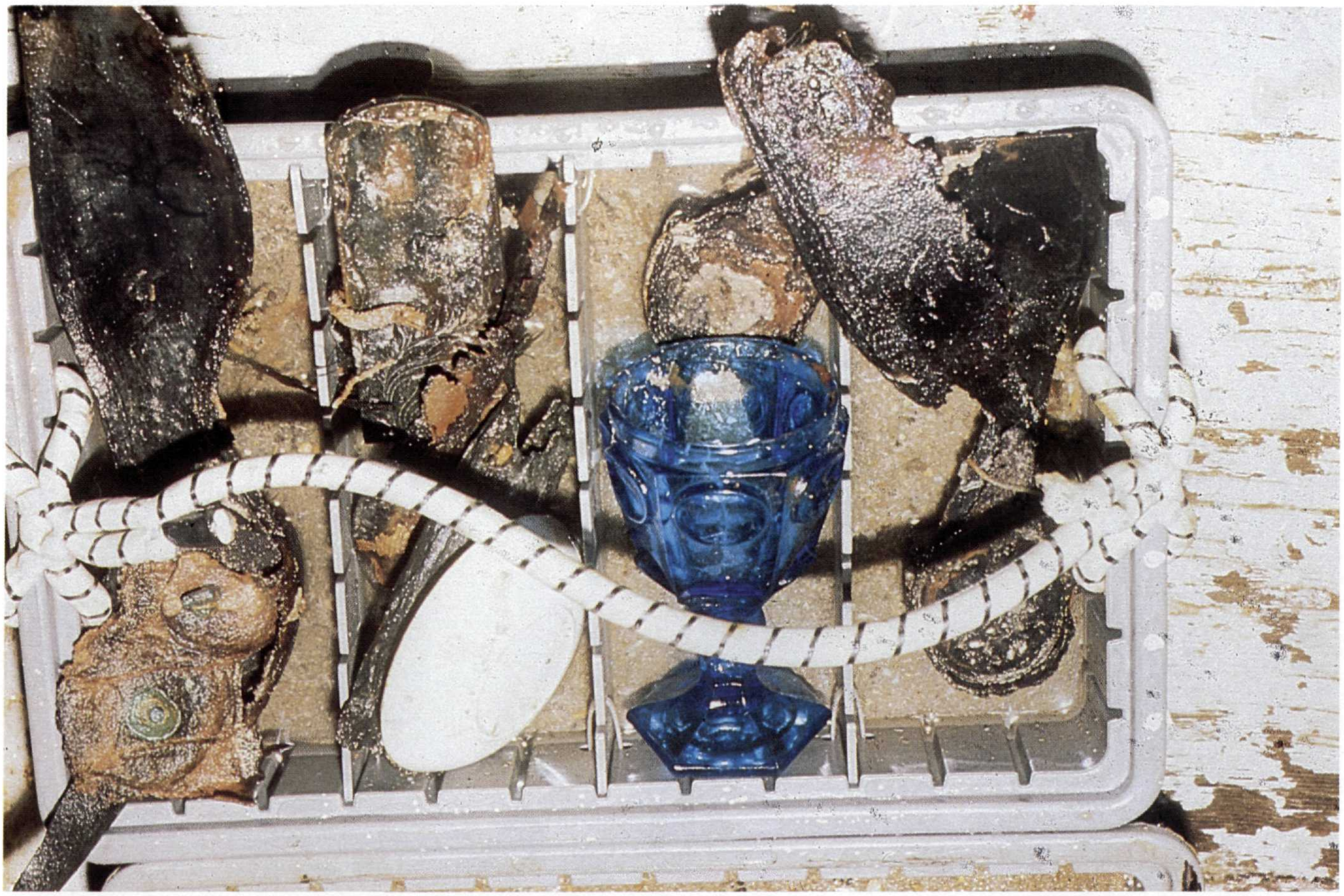


FIGURE 145. Plastic trays are used to recover artifacts from the shipwreck site. The trays are capable of being divided into 24 compartments. Each tray is given a number and each compartment is identified by a coordinate system. As each artifact is removed from the shipwreck, it is given an identification number and logged into a computer system from within the control room of the R/V *Arctic Discoverer*. Its location on the site and time of collection are also electronically recorded. On board the *Arctic Discoverer*, the artifacts are removed from the tray, tagged with its computer generated number, cataloged, and stored in way appropriate for the material. The artifacts in this tray were recovered from a disintegrated trunk and include a blue goblet (Artifact No. 29022), a white saucer (Artifact No. 29011), a hairbrush (Artifact No. 29328), and various trunk and leather footwear pieces (Artifact Nos. 29323, 29324, 29325, 29326, 29327).

DEEP-OCEAN TRANSFORMATION PROCESSES

Disintegration is a cumulative transformation process which continually influences the condition of a shipwreck. A wooden-hulled ship sunk in the sea is eventually consumed by marine life. Microorganisms, principally bacteria and fungi, slowly and invisibly break down the organic material of the ship, while wood-boring bivalves and isopods riddle the timbers. As microoganisms destroy the hemicellulose, water fills the lost space and allows the wood to retain much of its original shape (Pearson 1987). The chemicals in seawater accelerate corrosion of metal alloys.

When the search for the SS *Central America* began in the mid-1980s, very little information existed that could be used to predict how the shipwreck would appear after some 130 years in the ocean's abyss. Conceivably, all of the iron could have corroded away and the wood disintegrated. The only feature that was relatively certain to leave a signature was the several hundred tons of boiler coal in the hold.

As it turned out, what appeared on the video monitors was a seemingly chaotic wreckage that presented a major challenge in unraveling the transformation events that had resulted from her fall through 2,200 m of water and had occurred during 130 years on the seabed. Taking into consideration the configuration and mass of the ship and the characteristics of ocean, calculations of sinking dynamics indicated that the ship sank to the bottom in about 18 minutes, impacting the soft abyssal sediment at a speed of approximately 2.0 m/s (7.3 km/hr). The bow of the ship appeared to have hit the bottom first, striking with enough force to embed the hull 1 to 2 m into the sediment ooze, particularly along port side of the ship.

As the exploration progressed the main features of the shipwreck became more apparent and it was possible to sort out spatial relationships. As expected, coal was a major component of the site. Degradation processes were at work but at relatively slow rates. Many of the iron features of the ship (i.e., paddle wheels, engineworks, boilers, anchor chain, and water tanks) were easily recognizable even though their original position had been altered in some cases by sinking dynamics. The 10-m diameter port side wheel still projected high above the bottom (about 5 to 7 m) but was bent at an angle of about 45° (Fig. 61). The hull had collapsed outwardly and the decks appeared to be "sandwiched" together. Corrosion and the formation of iron rusticles continued to be an active biogeochemical process as demonstrated by the experiments discussed in the Materials Science section. However, the wooden parts of the ship had undergone transformation to a much greater degree than the ironworks. The hull had collapsed outwardly and laid flat on the seabed. As the sides of the ship fell away from the keel, they carried with them the hanging knees which stood pointing upward but rotated 90° from their original position (Figs. 63, 141). The knees, constructed of oak, survived in better condition than other wooden parts of the ship which were mainly of pine. As the hull fell away, the decks could have broken away from the knees and collapsed into the center of the ship or the decks may have already been detached from the hull when the ship hit the bottom; a survivor's account (George Dawson, *New-York Daily Tribune*, 6 October 1857) indicated that, as the ship sank lower and lower in the water during the ordeal, portions of the lower decks successively broke free and collided with the underside of the main deck. Structural failures, coupled with the later collapse of the hull yielded the rather flattened profile of the shipwreck, with the exception of the protruding ironworks. The degradation of the wood, particularly by deep-ocean borers, is discussed in the Materials Science section.

Leather objects, such as leather-bound trunks, survived surprisingly well in the deep ocean at the shipwreck site. Even more remarkable was the state of preservation of textiles and paper artifacts within the trunks. The seawater at the site was well oxygenated but it appears that the trunks were tightly enough sealed to restrict circulation and permitted reducing conditions to prevail inside.

The iron, wood, and coal of the site each provided a distinctive sonic and visual pattern which taken together gave the shipwreck its unique signature. Transformations over the past 130 years had created this signature and it will continue to be transformed as time progresses. Corrosion processes are still active, and to a somewhat-lesser degree wood degradation processes are ongoing. Thus, at least 130 years can pass in the deep sea before the signature of a complex ship disappears. Before accurate predictions can be made about older ships in the deep ocean (e.g., vessels of the 15th through the 18th centuries) it is necessary to add more data points to a timeline. However, the fact that the SS *Central America* has yielded remarkably well preserved artifacts, holds promise for discovering much older shipwrecks in the deep sea.

LIFE STYLES OF EASTWARD-BOUND PASSENGERS

The debris field surrounding the shipwreck of the SS *Central America*, an area of approximately 4 ha, was strewn with ship parts and passenger and crew articles. Of particular interest were a number of trunks, many of them standing upright (Figs. 146, 147). Two passenger trunks were recovered; the first was brought up near the end of the 1990 field season and the second at the end of the 1991 field season. They were retrieved by placing them in containers with lids and transporting them to the ocean's surface within the submersible. After a preliminary inspection (first trunk only), they were held in water until opened at a freezer facility on the campus of The Ohio State University. The first trunk was identified as belonging to Ansel Ives Easton and Adeline Mills Easton and the second to Lt. John D. Dement. All three were passengers who survived the tragedy.

FIGURE 146. Leather trunk in the debris field surrounding the shipwreck of the SS *Central America* (Artifact Nos. 29254, 29255). This trunk, subsequently recovered in September 1990, once belonged to honeymoon couple Ansel and Addie Easton.

The trunk owned by the Eastons was first examined in 1988 (Fig. 146). A jet of water was trained on the latch to blow away sediment so that an inscription could be read which caused the trunk to fall open. Each half was covered with a fabric flap that held the articles within the trunk even when the interior was exposed. The trunk lay in this configuration until September 1990, when it was recovered. The trunk halves were placed in separate Plexiglas® containers and moved to *Nemo*'s storage compartment (Figs. 148, 149). Because the containers were not completely watertight, it was necessary to add water during transport to the mainland. Onshore, a few of the trunk items were examined and found to be intact and recognizable clothing. Textile experts at The Ohio State University were contacted and preservation efforts were initiated (Figs. 150, 151). Building on the experience gained from recovering the Easton trunk, the second piece of recovered luggage (Dement trunk) was placed in a watertight container, sealed in ambient seawater, and refrigerated until it was opened. Remnants of several other trunks, including a possible physician's bag, were also investigated but the cases were so disintegrated that they could not be recovered intact.

Dr. Kathryn A. Jakes, polymer chemist with the Department of Textiles and Clothing at The Ohio State University, devised the procedure for investigating the contents of the trunks from the shipwreck site. Dr. Lucy R. Sibley, textile historian with the same department, and Charles Kleibacker, curator of the Historic Costume and Textiles Collection at The Ohio State University,

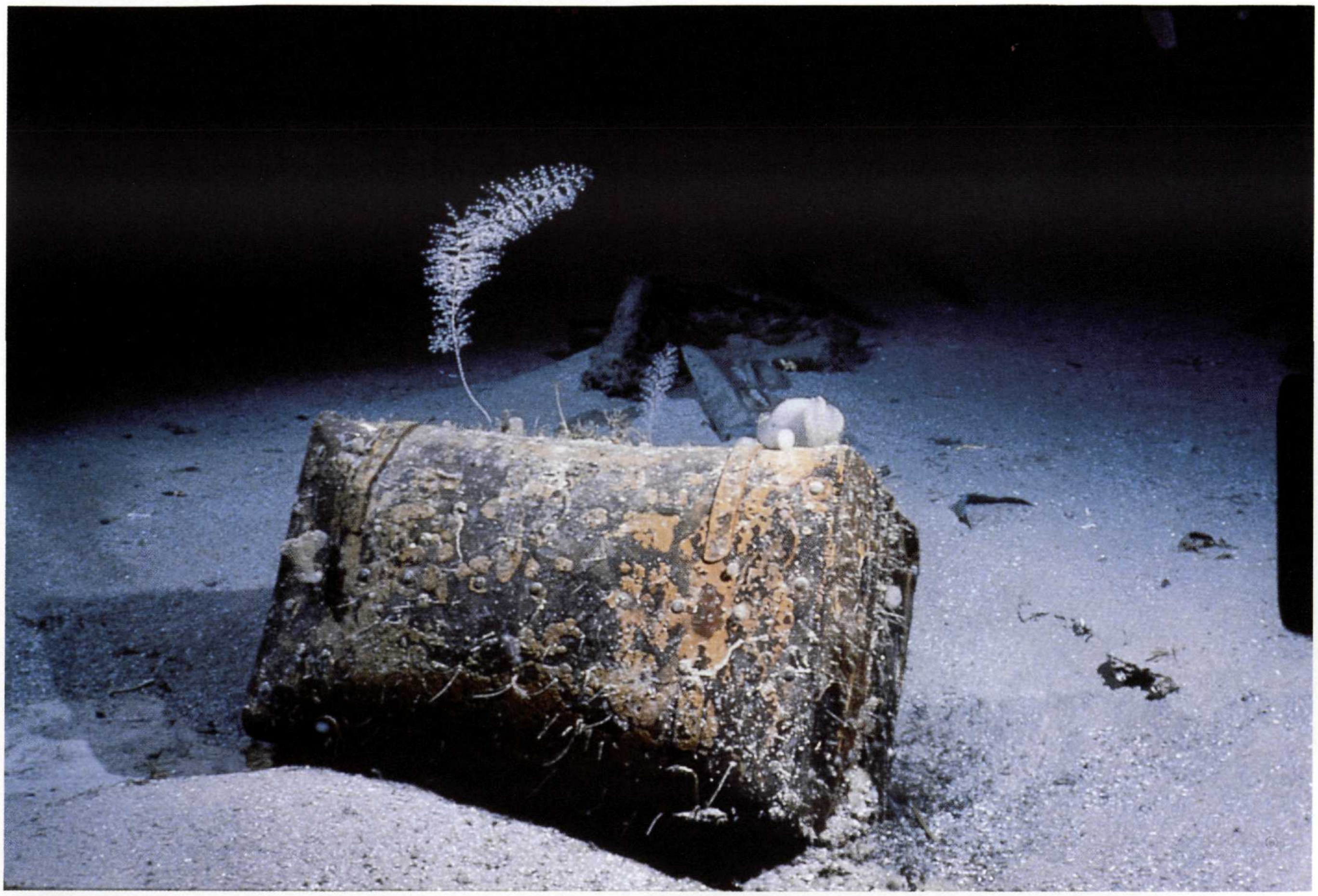


FIGURE 147. The second leather trunk to be recovered from the debris field (Artifact No. 33701). This trunk once belonged to an Oregon pioneer, John Dement. See Fig. 89 for a description of the marine life colonizing the trunk's surface.

aided in the direction of the trunk-opening operations. Members of Columbus-America Discovery Group collaborated in the opening operations and made videotapes and photographs of the contents. Drs. Jakes and Sibley, along with their students, conducted research in the areas of textile science and clothing history, including: 1) identification and characterization of the textiles from the trunks and of the stains which the fabrics contained, 2) determination of appropriate methods for preservation and conservation of the garments, 3) documentation of garment style, construction, and fabrics, and 4) interpretation of the historical significance of the garments as well as of the other artifacts

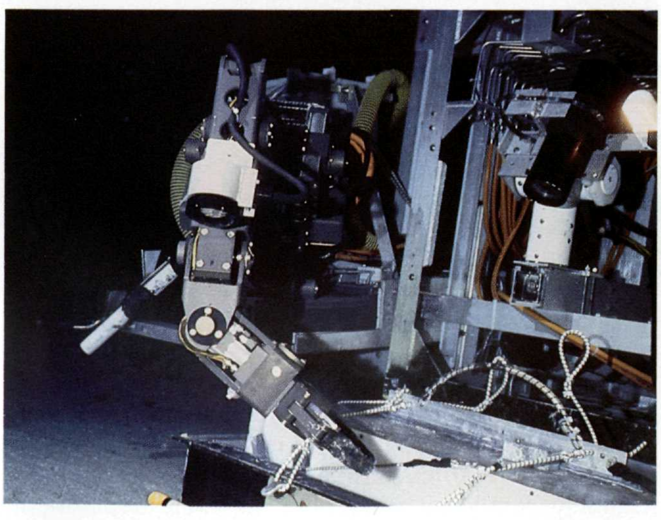


FIGURE 148. Plexiglas chamber containing one of the halves of the Easton trunk being placed in *Nemo*'s storage compartment.

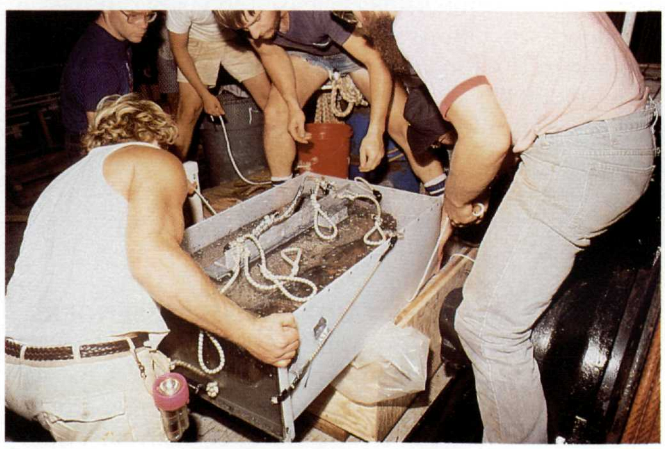


FIGURE 149. On board the R/V *Arctic Discoverer*, the Easton trunk is removed from the submersible's storage compartment and prepared for transport to The Ohio State University.

FIGURE 150. Opening of the Easton trunk at a freezer facility on the campus of The Ohio State University. One of the first items found in the trunk was a small pistol (Artifact No. 29204; see Fig. 158).

found in the trunks. To explore further the processes that alter textiles while in a marine environment, modern textiles were submerged at the deep-ocean site in 1991 for recovery and examination after differing periods of exposure (see Materials Science section).

Easton Trunk

The first passenger trunk recovered from the site was identified as belonging to Mr. and Mrs. Ansel Ives Easton, a well-to-do San Francisco couple on their wedding voyage to New York and on to Paris. While both men's and women's dress garments were recovered, about 85% were interpreted as belonging to Mr. Easton. At the time of the voyage, Ansel Easton was a man with a relatively high status in California. Hence, information gained about the style, function, and fashionableness of his dress, particularly his outerwear, could lead to a better understanding of the types of attributes used in men's fashionable dress to depict position and status during the mid-1850s. Based on this premise, Laurie C. Crawford, conducted doctoral research on the trunk's contents, under the direction of Drs. Sibley and Jakes.

FIGURE 151. Gloves recovered from the Easton trunk being bathed in deionized water (Artifact Nos. 29098, 29211).

A procedure was devised for the removal of each item from the black water contained in the trunk halves; this included immersion in demineralized water, unrolling while wet, assessment of item, sampling of fibers from inconspicuous locations, arrangement of the wet garment on framed Fiberglas® screens, and flash freezing at -28° C. The trunk-opening operation was videotaped and individual garments were photographed as they lay on the framed screens prior to deposition in the freezer.

The identity of the original owners of the trunk was a mystery until the clothing was unrolled and it was discovered that a number of finely stitched men's shirts displayed the inscription: "A. Ives Easton." In later examination of the garments, many other items were found to display Easton's name or initials (e.g., cuff of a pair of socks contains the initials: "A.I.E."). Also, a shirt was found, wrapped in newspaper, that had the inscription "W. Ralston." No one by that name was found on the passenger or crew lists. However, a William Chapman Ralston was a friend of the Eastons and a business partner of Adeline's brother Darius Ogden Mills.

Crawford (1994) found that six classes of outerwear were represented in the trunk: 1) coats, 2) waistcoats, 3) trousers, 4) neckwear, 5) shirts, and 6) collars. All of these classes, with the exception of waistcoats, were fashionable during the period 1853 to 1857 and represented styles manufactured and worn during this period. The waistcoats were older and represented styles manufactured in the late 1840s. They were also more colorful and patterned than other coats or trousers. All 42 men's outerwear garments appeared to be items a man of status would wear; they were somewhat conservative and formal with little variation in function. Most of the outerwear would have been worn for day dress; only two items, a white waistcoat (Artifact No. 29180; Fig. 152) and an embroidered shirt (Artifact No. 29065), would have been worn for formal or evening dress.

After organizing and analyzing the data according to Gardin's (1980) archaeological construct model, Crawford (1994) concluded that Ansel Easton indeed had outerwear that reflected his relatively high position, based on attributes visible in his dress. His shirts provided an excellent example of this finding; 13 of the 14 shirts were made of linen (flax fiber) while only one shirt was made of cotton. Linen shirts were a symbol of status during the mid-nineteenth century because they became soiled and wrinkled more easily than cotton shirts and required more effort to maintain (Fig. 153). Mr. Easton also had a variety of items that were made of silk fibers or had silk linings, such as the majority of his neckwear, three of his waistcoats, and linings from his coats and trousers. Most of his outerwear represented clothing that was worn for day dress. Perhaps other clothing representing different functions were packed in a different trunk; or perhaps a Panama Route voyage in the mid-nineteenth century did not require a different type of dress for evening social functions.

In addition to men's clothing, a few women's garments were also packed in the trunk. Chemises, petticoats, bloomers, a dressing gown (Fig. 154), a morning

FIGURE 152. Men's evening-dress waistcoat recovered from the Easton trunk (Artifact No. 29180).

robe, and several pairs of stockings were among such items. Other items included a gold and quartz watch fob (Artifact No. 29200; Fig. 155), a dog's-head fob with red stone eyes (Artifact No. 29197; Fig. 156), a small box with Oriental carving (Artifact No. 29124), a bottle of double distilled "Bay Water" (Artifact No. 29061), three cologne bottles (Artifact Nos. 29245, 29248, 29250), a gold buckle (Artifact No. 29263), two quill pens (Artifact Nos. 29297, 29298), and ambrotype portraits (an early positive photograph made by a collodion process on glass and viewed against a dark background) (Artifact Nos. 29123, 29209; Fig. 157).

The Easton trunk also contained what is thought to be a set of dueling pistols (Artifact Nos. 29204, 29205) and a gunpowder flask (Artifact No. 29199) (Figs. 158, 159). Pistols such as these were often concealed in the pocket of a vest or coat and were deadly at close range (Peterson 1967). Laurie C. Crawford, Department of Textiles and Clothing, The Ohio State University, analyzed the remaining ornamental plates and indentations made by the missing plates on the pistols and determined that the pistols could have been Deringer pistols made by Henry Deringer. The decorative etchings matched those of the Deringer make (Flayderman 1983). Henry Deringer made approximately 8,000 such pistols between 1852 and 1868 (Peterson 1967) but there were many imitators, often marking their pistols as "derringers." Several of the metal pieces from the pistols were missing but the wood appeared to be solid. The pistols were kept in deionized water to keep the wood from collapsing and shrinking. As waterlogged wood degrades, it often loses some of its cellular structure without losing the object's shape because water serves as a support system, filling in the spaces where the wood's cellular structure has been lost (Pearson 1987). The pistols also had many areas of rust scattered across the stocks. The rust may have come from the missing barrel and lock or from other oxidizing metals in the trunk. Since the metal in Deringer pistols was typically silver, it is likely that the rust came from some other ferrous metals near the pistols in the trunk.

A second Easton trunk is believed to be located somewhere on the shipwreck site, based on a letter written by Adeline Easton to her friend Jenny Page of San Francisco on 4 October 1857, "My large trunk, I never saw it after it left your house. You know it had many precious things in it, to me. My watch, my beautiful ring, wedding presents and many other things I valued from their association were all lost." (Lincoln 1911, Noonan 1992a). The Eastons were among the wealthiest and most socially prominent passengers on board the *Central America.*

FIGURE 153. Men's linen dress shirt with collar recovered from the Easton trunk (Artifact No. 29066).

FIGURE 154. Women's dressing gown recovered from the Easton trunk (Artifact No. 29060). The Easton trunk contained many articles of clothing belonging to both Ansel and Addie Easton. As garments were removed from the trunk, they were carefully unrolled on specially constructed frames over which sheets of Fiberglas screening were stretched. The frames were then placed in a freezer that was held at a constant -28° C until the garments were completely dried. Drying was determined by periodically weighing the garments and noting the weight loss. When a stable weight was achieved, the garment was dry.

FIGURE 155. Gold and quartz watch fob recovered from the Easton trunk (Artifact No. 29200).

Dement Trunk

John Dement spent 13 hours in the water before becoming one of the last two people rescued by the bark *Ellen* (9:00 AM on Sunday morning, 13 September 1857). An interesting coincidence links the two trunks that were recovered from the SS *Central America* site. John Dement was saved because Ansel Easton, rescued shortly before, convinced Capt. Johnsen to make one more tack in an effort to find his friend Robert T. Brown. When the *Ellen* succeeded in finding Brown, Dement was in his company. A nineteenth-century article described Dement as: "a muscular, well-built man, rather above the average stature, with strong nerves, and apparently he is capable of retaining his presence of mind in emergencies—to which qualities he has been indebted under Providence for the Preservation of his life on several occasions" (Barrows 1897). The year prior to the sinking, he had been aboard both the *Texas* and the *John L. Stephens* in heavy gales that were: "as severe as that in which the *Central America* was lost."

John Dement was a merchant and railroad warehouse owner from Oregon City, OR, who was traveling to Baltimore, MD (Barrows 1897). As with the Easton trunk, the identity of the original owner of this trunk was at first unknown. The mystery ended in February 1992 when documents from the trunk had dried to the point

FIGURE 156. Dog's-head watch fob, with ruby eyes, recovered from the Easton trunk (Artifact No. 29197).

FIGURE 157. An ambrotype photograph of an unidentified young man, recovered from the Easton trunk (Artifact No. 29123).

where they could be inspected. A letter of introduction revealed the trunk's owner. The letter was written by J. A. Simms to B. Lancaster of Baltimore, MD, and stated: "Allow me to introduce to you Mr. John Dement of Oregon City. Mr. Dement is one of our largest merchants here . . . I have given him this hoping that you would introduce him to such of my friends as may be in Baltimore while he is there . . ." (Artifact No. 33850).

The recovery of the Dement trunk provided an opportunity for one of Dr. Sibley's graduate students, Susan L. Hannel, to study the contents as they related to the production and acquisition of clothing in a growing Pacific Northwest town during the mid-1850s. On 17 October 1991, after being held for two weeks at approximately the same temperature as the seafloor, the trunk was opened at The Ohio State University. Prior to opening the trunk, biological specimens were removed from the outer surface of the trunk and placed in preservative solutions. The entire process of the trunk unpacking was recorded on videotape. Once the trunk was opened, the location of each individual item in the trunk was defined in spatial coordinates (i.e., x, y, and z) and photographed *in-situ*. The items were then removed, unrolled, and assessed in a manner similar to that used for the Easton trunk items.

Hannel (1994) selected 10 outerwear textile products for study which represented a range of style, fabrication, and construction of garments found in the trunk. These included one lined wool frock coat (Artifact No. 33775), two unlined linen sack coats (Artifact Nos. 33782, 33785), one unlined cotton sack coat (Artifact No. 33780), one wool vest (Artifact No. 33776), one shawl collar silk vest (Artifact No. 33708), one cotton piqué shawl collar vest (Artifact No. 33710), and three pairs of linen pants (Artifact Nos. 33801, 33807, 33816; Fig. 160). Other garments in the trunk included underwear, shirts, collars, neckwear, and footwear. All of the garments studied were found to be hand sewn and custom made except for two of the sack coats (Artifact Nos. 33780, 33785), which were also hand sewn but probably ready or home made. The selected articles were garments advertised in Oregon newspapers in the mid-1850s and other period documents. This assessment indicated that all of the garments were available from Portland, OR merchants and could have been purchased locally by Mr. Dement.

In addition to 64 articles of clothing, the trunk contained a considerable amount of tobacco leaves and cigars (e.g., Artifact No. 33728), presumably obtained during the stop in Havana a few days before the sinking.

FIGURE 158. Pair of Deringer pistols recovered from the Easton trunk (Artifact Nos. 29204, 29205).

FIGURE 159. Gunpowder flask with embossed eagle, from the Easton trunk (Artifact No. 29199).

Also packed in the trunk were three novels (Artifact Nos. 33734, 33738, 33739), a shaving kit (Artifact No. 33735; Fig. 161), a newspaper (*The Sunday Varieties*, San Francisco, 16 August 1857; Artifact No. 33737), a ledger containing a "Wells Fargo & Co." envelope (Artifact Nos. 33757, 33892; Fig. 162), a checkbook (Artifact No. 33758), and other personal items. Dement's financial documents showed that he was a successful merchant, with transactions in the hundreds of dollars and a balance of $2,406.92.

SHIPBOARD ENVIRONMENT

During the early part of the September 1857 voyage, between Panama and the Straits of Florida, passengers enjoyed a comfortable cruise and fine weather by strolling the spar deck, reading books and newspapers, playing whist and other games, and getting acquainted with fellow passengers (Klare 1992, *Harper's Weekly*, 3 October 1857). The cabins were small and the dining saloon was compact, making the spacious spar deck a favorite place in good weather. Artifacts recovered from the site provided more detail on shipboard activities. Three books were found in the Dement trunk: *Count of Monte Cristo* (Artifact No. 33739), *Prairie Flower* (Artifact No. 33734), and *Lady Lee's Widowhood* (Artifact No. 33738; Fig. 163). The last was a light romance written in 1850 by Sir Edward Bruce Hamley, a British army officer (Noonan 1992a). In the Easton trunk was a well-preserved 20 July, 1857 edition of the *New York News* (Artifact No. 29206). Waterlogged for over 130 years, the newspaper was still readable (Fig. 164). The paper was a special steamer edition printed in New York City for delivery via steamship to California. Considering that the *Sonora* departed San Francisco on 20 August and that it took nearly a month for the paper to reach California via the steamer route, the paper must have been purchased just before the voyage. After undergoing a slow drying process while in a frozen state, the newspaper was assessed by Harry Campbell, Department of Collection Maintenance, The Ohio State University Libraries. Under his direction, the newspaper was humidified and flattened, torn areas were bridged, and the paper was enclosed between two polyester sheets and mounted behind ultra-violet absorbing Plexiglas plates. This arrangement allowed viewing of the obverse and reverse sides of the paper while preserving the condition.

Games and toys were also represented in the recovered artifacts, including parts of a checkerboard set (Artifact Nos. 33846, 33885, 33886, 34019) and a rubber doll (Artifact No. 33689). Pieces of a checkerboard set, consisting of 23 wooden squares and two wooden checkers, were collected in 1991 in the vicinity of a disintegrated trunk. After being bathed in deionized water, a test was conducted on four of the squares and the two checkers by placing them in an acetone bath

FIGURE 160. Men's white linen pants, with 5-button fly, recovered from the Dement trunk (Artifact No. 33807).

FIGURE 161. Leather shaving box recovered from the Dement trunk (Artifact No. 33735).

for one day and then in tetraethylorthosilicate (TEOS) for an additional day (Irwin and Wessen 1976). When the test items were removed from the solvent and dried, they had a white, powdery deposit (possibly silicone) on them that was easily removed by gentle brushing. There was no apparent loss in size. The treatment was then used on the remaining squares and the entire set was displayed in the Columbus Museum of Art, Columbus, OH, during the summer of 1992. However, after the exhibit, it was noted that although dimensional stabilization was achieved, the squares were very dry and brittle and some iron oxide appeared. Based on the results of this test and the work of Grattan (1982), the above treatment was not used for other wood objects from the site.

The doll was hollow, 30 cm long from toe to neck (the head was missing), and 21.9 cm wide at the point of maximum breadth. The body had collapsed, presumably under the high pressure at the sea floor, which may have dislodged the doll's head from the body (Fig. 165). Similar dolls from the mid-nineteenth century had round, solemn, hand-painted faces (Coleman et al. 1968). The rubber doll was fragile and in poor condition, with many cracks spread across the body. There was a hole in the stomach and the left arm was nearly detached from the body. The back bore a circular mark with the words: "Goodyear's patents 1848 & 49/A Rubber Company." Charles Goodyear patented a process for making hollow articles made of vulcanized India rubber in 1848 (U.S. Patent No. 5536). Natural rubber (polyisoprene) contains unsaturated carbon-carbon bonds that are retained throughout the vulcanization process (Billmeyer 1984). As rubber ages, these bonds can be broken by oxygen through a natural autocatalytic process which results in softening and embrittlement. This process, combined with free ions of chloride and bromide in the seawater, can irreversibly alter submerged rubber objects, such as the doll. Since its recovery in 1991, the doll has been stored in deionized water but it has not stabilized and has progressively deteriorated as the rubber slowly crumbled. Artifact conservation literature contains few references to submerged rubber but treatment with an epoxy may show some promise.

Tableware articles were common artifacts observed at the shipwreck site and helped to recreate mealtime on the *Central America*. Cabin passengers may have been called to dinner with a small brass bell (Artifact No. 29023). They ate food served on ironstone china dinnerware (e.g., Artifact No. 29003), drank from crystal goblets (e.g., Artifact No. 29028), and poured seasonings from cut glass cruets (e.g., Artifact No. 33666). Other glassware artifacts included clear crystal decanters (e.g., Artifact No. 29036) and a blue goblet (Artifact No. 29022). The latter was found in the remains of a disintegrated trunk and probably was not part of the normal shipboard glassware (Fig. 145). Beverage bottles recovered from the shipwreck indicated that passengers drank beer and wine (e.g., Artifact Nos. 33673, 33678); a blue-green, wine-tester bottle suggests that wine may have also been carried in casks (Artifact No. 8003, Fig. 166). In the evening, the dining saloon may have been illuminated with a copper alloy whale-oil lamp (Artifact No. 29027).

A number of containers made to hold food and beverages were found on the shipwreck. Most of these artifacts were glass beer and wine bottles (Fig. 142) but a few were stoneware (Fig. 167). One of the latter type, a brown stoneware bottle, carried the molded label: "VITREOUS STONE BOTTLES, –/WARRANTED NOT TO ABSORB/J. BOURNE & SON,/PATENTEES/DENBY & CODNOR-PARK POTTERYS/NEAR DERPY" (Artifact No. 29021). Another container, a small pitcher, had a wicker "collar" around the neck (Artifact No. 33834). The pitcher appeared to be of an Oriental design (Fig. 168). The wicker was air dried and displayed with the pitcher at the Columbus Museum of Art, Columbus, OH, during the summer of 1992. When signs of excessive dryness were noted, the wicker was treated with a polyethylene glycol solution (PEG 400) to preserve the wood and keep it from separating from the bottle. The solution was gently brushed on the wicker to preserve the integrity of the wicker design. This process was repeated daily for one week, with the bottle stored under a glass dome to keep it free from dust. The wicker was treated a second time four months later. At the end of this treatment, the wicker took on a dark brown color and regained its flexibility.

FIGURE 162. Wells, Fargo & Co. envelope found in a ledger from the Dement trunk (Artifact No. 33892 – envelope).

Cabin class passengers enjoyed the best accommodations on the *Central America* but even the First and Second Cabin areas lacked bath or shower facilities. However, based on the large quantity of toilet articles observed on the site, each cabin probably had a set of ironstone china toiletry including a water pitcher, wash basin, a soap dish with a lid and drain, and a chamber pot (e.g., Artifact Nos. 29000, 29001, 29007, 29016) (Fig. 169). Personal hygiene and grooming articles recovered from the site included soap (Dement trunk, Artifact No. 33761), a feminine douche (Easton trunk Artifact No. 29195; Fig. 170), shaving kit and cream (Artifact Nos. 29017, 33735), and a jar containing: "HIGHLY PERFUMED BEAR'S GREASE For Beautifying & Strengthening the Hair" (Artifact No. 29018) (Fig. 171). What is believed to be a degraded doctor's bag was also investigated and found to contain a glass syringe (Artifact No. 33836) and several medicine bottles, one with the inscription: "DAVIS VEGETABLE PAIN KILLER" (Artifact No. 33838).

Items of personal adornment were also found in the debris field of the shipwreck. A particularly attractive artifact was a women's ring originally set with six different gemstones (Artifact No. 29041). Historical research showed that this type of ring was given as token of affection, perhaps as a friendship ring would be given today. They were popular in the mid-nineteenth century

FIGURE 163. A novel, *Lady Lee's Widowhood*, recovered from the Dement trunk (Artifact No. 33738).

FIGURE 164. Steamer Edition of the *New York News* 20 July 1857 found in the Easton trunk (Artifact No. 29206). When the newspaper was unrolled it was found to contain a men's dress shirt (Artifact No. 29114).

(Bury 1984, Flower 1969, Gere 1975). The different gems were used to spell out sentiments. In this case, the first letters of the gemstones spell out the word "REGARD": ruby, emerald, garnet, amethyst, rose quartz, and diamond (Fig. 172). The ruby was missing when the ring was recovered.

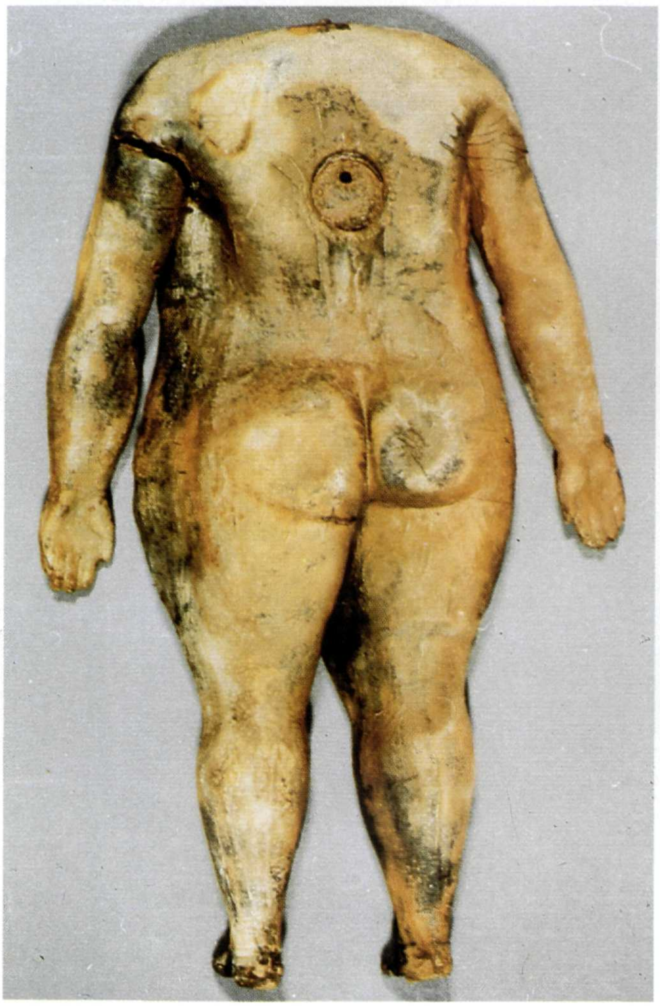


FIGURE 165. India-rubber doll recovered from the shipwreck (Artifact No. 33689).

Another artifact, this one symbolizing a personal accomplishment, was found resting on a collapsed knee of the ship (Figs. 141, 173). The item was a cross-shaped medal presented by the Italian government as an award of honor (Artifact No. 33691) and was determined to be a badge of the now obsolete Order of St. Maurice and St. Lazarus. This Order, founded in 1434, was conferred by the King on persons distinguished in the public service, science, art, letters, trade, charitable works, and military or naval service (Dorling 1974).

FIGURE 166. A wine-tester bottle recovered from the shipwreck (Artifact No. 8003).

The badge was a Maltese cross placed saltire-wise, green, edged gold with gold knobs on the points (representing St. Lazarus), and surmounted by an enameled white, botonée-shaped cross (representing St. Maurice). The enamel appeared to be a vitreous glaze fused to a gold base in which the green and white colors were applied using the champlevé technique (Robins 1982). There were five classes of the award: *Knights Grand Cross*, with star on the breast and broad ribbon over the shoulder with the badge on the hip; *Knights Commanders*, with star on the breast and badge around the neck; *Commanders*, with badge around the neck; *Officers;* and *Knights*, the latter two with badges on the breast. Dorling (1974) noted that badges of the first

FIGURE 167. A stoneware bottle recovered from the shipwreck site (Artifact No. 29021). At least ten serpulid worms (possibly *Ditrupa* sp.) have colonized this surface, including a 3-cm long specimen (white tube) near the center of the bottle.

four classes had a Royal Crown above them. Because the provenience of the badge was an isolated part in the wreckage, no ribbon was found and the class could not be determined (Fig. 141). However, the clasp structure at the top the botonée cross appeared to be of the type that attaches to a breast ribbon. The identity of the owner is unknown but at least two Europeans were on board, Pasqual Esquema from Spain and Ange Richon from France.

NUMISMATIC PRACTICES

The numismatic artifacts recovered from the site included thousands of gold coins and hundreds of gold specie ingots, as well as gold dust, flakes, and nuggets (Noonan 1992b) (Fig. 174). Gold nuggets and dust were recovered with a specially designed suction dredge, "Sea Vac," which also uncovered significant quantities of gold bars and coins. The dredge retained dense material, such as gold, and rejected the lighter shells of the sediment ooze. One outstanding recovery was a large gold nugget encrusted with quartz crystals, most likely eroded from a California hillside and deposited in a stream bed shortly before a fortunate miner found it and brought it along on this fateful voyage.

The numismatic objects at the site ranged from tiny gold quarter-dollar coins to gold bars weighing hundreds of ounces each. The coins and bars presented an unprecedented glimpse of monetary practices and trade in the mid-nineteenth century, particularly in the early statehood period of California (Breen 1990, Yeoman 1993). The categories of numismatic objects recovered from the shipwreck included:

1. Coins of all the United States mints of the mid-1850s (the branch mint at San Francisco, the main mint in Philadelphia, and other branch mints in New Orleans, Charlotte, and Dahlonega, GA);
2. Gold coins minted by pioneer assayers and coiners during the years 1849 through 1855 (Fig. 175);
3. Gold coins of minute dimension, produced by San Francisco jewelers to provide pocket change (e.g., quarter dollars) for an economy where small coinage was scarce;
4. Gold specie ingots molded and stamped by pioneer assayers—the first step in manufacturing a monetary form for the raw gold from the mines and a medium of exchange for large commercial transactions;

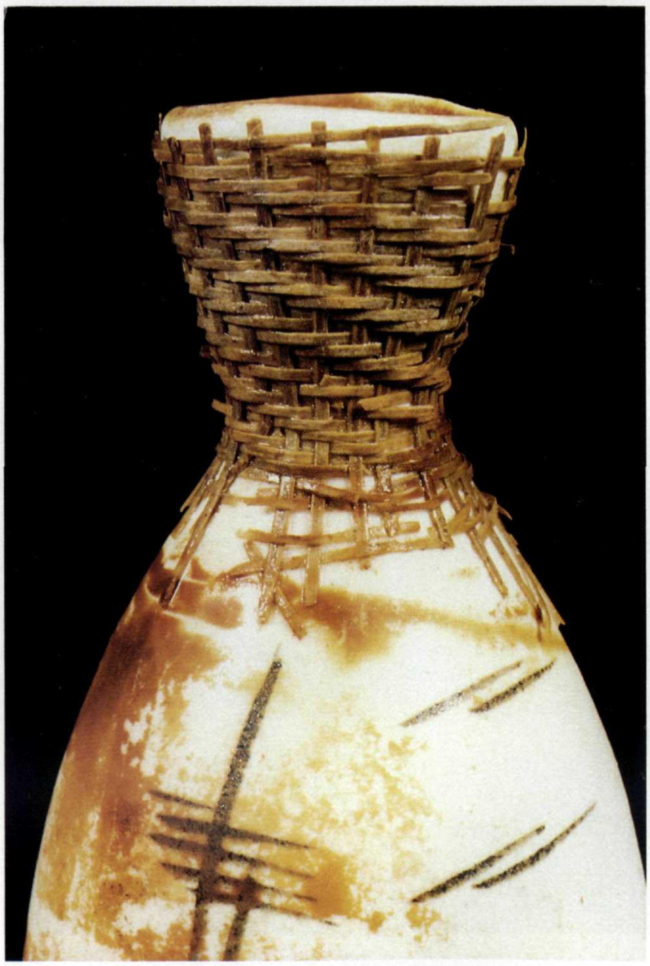


FIGURE 168. Oriental-design pitcher, with wicker collar, recovered from the seabed at the shipwreck site (Artifact No. 33834).

5. Foreign coins from various nations (gold coins from France, Germany, and Great Britain and silver coins from Bolivia, Chile, and Mexico); and
6. Counter-stamped coins (coins struck with a stamp either as advertising for a business or as a denominational indicator for use in foreign economies).

Gold Coins

Most of the gold coins retrieved from the shipwreck site were mint-state 1857-S double eagles (0.9675 troy ounces of gold; face value of $20). One of the more remarkable finds was "the tower,"—a neatly stacked pile of about 300 double eagles. Originally, these may have filled a wooden box which was disintegrated by wood-boring bivalves. Calcium carbonate from the seawater and iron oxides from the rusting steam engines had lightly encrusted the coins of the tower, weakly "cementing" them enough to withstand the forces of the gentle currents. The entire tower was recovered intact using a silicone compound which was injected into a mold placed around the gold (Figs. 48-51).

FIGURE 169. Ironstone toiletry set recovered from the shipwreck (Artifact No. 29000 – pitcher; No. 29001 – wash basin; No. 29019 – strainer lid; No. 29020 – soap dish).

FIGURE 170. Feminine douche kit (elastic injecting instrument) in a fabric-covered purse, found in the Easton trunk (Artifact No. 29195).

Many of the coins and bars from the site were stained by a surface film of iron and other chemicals. As a noble metal, the gold did not appear to react chemically with the encrusting material. A tri-sodium method (sodium citrate/sodium thiosulfate/sodium bicarbonate solution) developed by Waller (1980) to remove iron oxides from acid-soluble mineral specimens was employed to lift off iron oxides without disturbing their mint luster—leaving the coins in the same condition as when they were shipped.

Other noteworthy coins included 1857-S eagles, half eagles and quarter eagles (i.e., $10, $5, and $2.50 gold pieces), 1856-S $3 gold pieces, and rare pioneer coins (Fig. 175) which were struck by private California firms before the federal mint was opened in 1854 and until 1856, when the mint could not keep up with the demand for small denomination coinage (Kagin 1981). Well-worn federal coins date back to 1834 (half eagle) and cover most of the years in between. Only a few silver coins were found, including a U.S. half dollar with a Chinese counter stamp or "chop mark." Also brought up were a British sovereign and other European gold coins of the period, the oldest being an 1825 ten-thaler piece from Hannover (former German state which was absorbed by Prussia in 1866) (Breen 1990).

FIGURE 171. Ceramic jar lid recovered from the shipwreck (Artifact No. 29018).

Gold Specie Bars

The nature of monetary bars made during the Gold Rush period was largely conjectural until several hundred gold ingot bars were recovered from the shipwreck of the SS *Central America* (Yeoman 1993). When the San Francisco branch mint opened in 1854, it lessened the need for private assay companies but in 1857 at least 15 were still operating in the state. California assayers offered several services to their customers. When gold dust and nuggets were found, these companies would melt and assay the gold for a fee. The raw gold was cast into bars and stamped with weight, fineness, serial number, dollar value, and the assayer's name or hallmark. The customer would receive payment for his original deposit either in coins or bars, minus the assayer's fee. Miners who did not want to pay the assayers' premium to convert gold into coins, often converted it into bars which were transported to the United States Assay Office in New York, or to the Mint in Philadelphia, to realize a better rate than they could get in California. Some bars of this type, known as "conversion ingots," were found on the SS *Central America* shipwreck. Such bars were used in banking and business transactions involving large sums of money. Many Eastern banks, and probably the Mint's own Assay Office, routinely shipped similar large ingots by steamship from California to New York for credit to the owners' accounts (Yeoman 1993).

FIGURE 172. A nineteenth-century friendship ring recovered from the shipwreck (Artifact No. 29041). In this type of ring, different gems were used to spell out sentiments. Here, the first letters of the gemstones spell out the word "REGARD" – ruby, emerald, garnet, amethyst, rose quartz, and diamond. The ruby was missing when the ring was recovered.

The specie bars recovered from the site ranged from a few ounces to ones weighing several hundred ounces (Fig. 174). These included the largest gold ingots known to have been recovered from a shipwreck. Typically, each bar had several distinct features:

1. The manufacturer's mark (e.g., "Justh & Hunter") was stamped on the surface;
2. A beveled surface at one or more corners (assayers removed corners to test the gold's purity and from which they took a fee, or "cut"), which at times bore an additional mark (e.g., "J & H" to prevent the shaving of gold from the cut);
3. An identification number, commonly of several digits, was stamped on the surface and an additional number (all or the last few digits of the surface number) was placed on the underside, which permitted the ingot to be tracked through the manufacturing process (e.g., "No. 4267" on the front and "67" on the back);
4. The fineness or purity of the gold was stamped on the front, usually expressed in thousandths (e.g., "876 FINE" which means 87.6% pure gold);

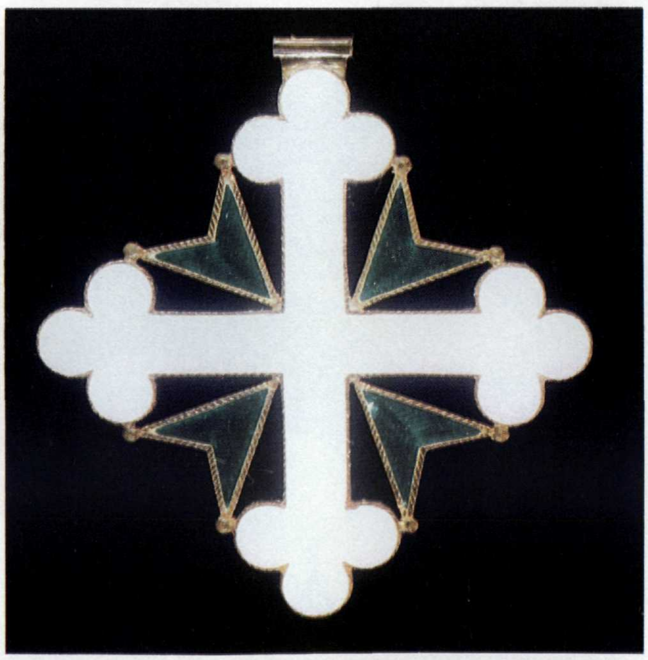


FIGURE 173. A medal from the Italian Order of St. Maurice and St. Lazarus recovered from the shipwreck (Artifact No. 33691; see Fig. 141).

FIGURE 174. Representative gold ingots (bars), coins, and nuggets recovered from the SS *Central America* shipwreck.

FIGURE 175. A pioneer gold coin recovered from the SS *Central America*. This $50 gold piece was minted in California in 1851. Sunk into the octagonal edge is the notation: "AUGUSTUS/HUMBERT/UNITED/STATES/ASSAYER/OF GOLD/CALIFORNIA/1851." Augustus Humbert, a former New York watch-case maker, was appointed United States Assayer and he was authorized to place his name and the government stamp on gold pieces issued by Moffatt & Co. This measure was taken as a temporary expedient to accommodate California until the establishment of a permanent branch mint in 1854. These coins were accepted as legal tender on a par with standard U.S. coins and were variously known as slugs, quintuple eagles or five-eagle pieces. They were officially termed an ingot. The notation: "880 THOUS," indicates that gold accounted for 880 parts out of a 1,000 parts of the metal alloy in the coin. The coin weighs approximately 2.5 oz.

TABLE 21

Representative gold specie bars recovered from SS Central America *site.*

Blake & Co.
- No. 5190: Blake & Co.; 4.95 oz.; 795 FINE; $81.34; 37 x 20 x 10 mm
- No. 5213: Blake & Co.; 16.75 oz.; 722 FINE; $249.99; 88 x 20 x 15 mm

Harris, Marchand & Co.
- No. 6488: Harris Marchand & Co.; 13.52 oz.; 807 FINE; $225.54; 48 x 30 x 15 mm
- No. 6524: Harris Marchand & Co.; 22.52 oz.; 878 FINE; $408.73; 51 x 42 x 17 mm

Henry Hentsch
- No. 3068: Hy. Hentsch; 12.52 oz.; 973 FINE; $251.82; 55 x 30 x 10 mm

Justh & Hunter
- No. 4343: Justh & Hunter; 22.83 oz.; 883 FINE; $416.72; 61 x 43 x 15 mm
- No. 4251: Justh & Hunter; 16.83 oz.; 864 FINE; $300.59; 56 x 34 x 16 mm

Kellogg & Humbert
- No. 810: Kellogg & Humbert Assayers; 23.34 oz.; 898 FINE; $433.26; 40 x 51 x 18 mm
- No. 554: Kellogg & Humbert Assayers; 36.68 oz.; 864 FINE; $690.84; 7 x 44 x 15 mm
- No. 962: Kellogg & Humbert Assayers; 208.10 oz.; 874 FINE; $3,759.78; 147 x 65 x 40 mm

Note: Current values were not assigned to these bars because of their unique nature.
Data Source: Yeoman (1993).

5. The weight in hundredths of a troy ounce was also stamped on the front (e.g., "15.31 OZ"); and
6. The value in dollars and cents was stamped on the face of the ingot (e.g., based on its fineness and weight the bar with the above characteristics was stamped with an 1857 value of "$277.21"—in 1857 pure gold was valued at $20.67 per troy ounce).

If it were not for the tragic sinking of the SS *Central America*, examples of these ingots wound not be available for study. If they had reached their destination, the bars would have been deposited in New York or turned into coins. On the other hand, if the bars had remained in California, they would have been melted down and turned into coins at the San Francisco Mint, once it got into full production (Yeoman 1993). A sampling list of gold specie bars recovered from the *Central America* shipwreck is presented (Table 21). These ingots were cast by five California assaying firms: 1) Blake & Co., 2) Harris, Marchand & Co., 3) Henry Hentsch, 4) Justh & Hunter, and 5) Kellogg & Humbert. In 1854, the firm of Blake & Co. was opened by Gorham Blake in Sacramento at 52 J Street (Kagin 1981). Harvey Harris and D. Marchand operated assay offices under the name of Harris, Marchand & Co. in Sacramento and Marysville for a short period of time during the 1850s but never issued circulating coins. The Assay Office and Banking House of Henry Hentsch operated from 1857 to 1858 at 120 Montgomery Street, San Francisco. His advertisements for assaying appeared in major newspapers of the day. The San Francisco and Marysville offices of Justh and Hunter operated from 1855 to 1856. Justh was a Hungarian refugee, probably from the Kossuth Revolution of 1848 to 1849. Fellow Hungarian assayers and coiners Samuel C. Wass and Agoston P. Molitor produced pioneer gold coins that were also recovered from the shipwreck. Kellogg & Humbert operated an assay office and mint from April 1855 to 1866 at No. 104 Montgomery Street, San Francisco. Partners in this firm were John Glover Kellogg, a former Moffatt & Co. employee, and Augustus Humbert, formerly U.S. Assayer of gold in San Francisco.

CONCLUSIONS

The steamer *Central America* sank on 12 September 1857 en route from Panama, via Havana, Cuba, to New York City. The ship fought the fury of a North Atlantic hurricane for 30 hours before sinking at a position some 270 km off the Carolina coast in 2,200 m of water. She carried 476 passengers, a crew of 102 and a cargo of more than three tons of California gold. The gold and 425 lives were lost in the disaster, the worst maritime tragedy on the high seas in American history. Assessment of historical documentation (including eye-witness and survivor accounts), mathematical probability mapping, and side-scan sonar surveying proved to be an effective methodology for locating the shipwreck at a depth of 2,200 m. Likewise, the development of a deep-ocean, remotely operated submersible proved to be a splendid technique for discovery, mapping the site, and recovery of specimens and artifacts.

The discovery of the shipwreck of the SS *Central America* presented scientists of many disciplines with an unusual opportunity to investigate deep-ocean phenomena at an unusual site. The shipwreck was a small (4 ha), biogeochemical/anthropological anomaly on the Blake Ridge, a monotonous sedimentary deposit. At abyssal depths on the Ridge, anomalies of this type were found to be rare, isolated, and virtually unstudied. At 2,200 m, the mean temperature was 3.4° C, salinity 35‰, pressure 220 atm, dissolved oxygen 6 ml/l (83% saturation), and pH 8.1. The Deep Western Boundary Current flowed southerly through the site at an average velocity of 10 cm/s. Sediments surrounding the shipwreck lacked terrigenous components and consisted largely of a *Globigerina* and pteropod ooze at a ratio of 5:1. The sedimentation rate as determined by radiocarbon dating was 1.7 cm/1,000 yr.

The wooden-hulled steamship, with its hundreds of tons of iron machinery, had undergone extensive transformation during its 130 years on the seafloor. The wooden members had largely collapsed and many timbers were decomposed as a result of wood borers and microbial activity. Two new species of large, tube-forming pholadid bivalves (up to 40 cm long) are believed to be responsible for most of the wood destruction. The ironworks had undergone severe corrosion, including the formation of bacteria-mediated flow structures called rusticles, but their original functions were still discernible. Iron-oxide scales also stained much of the rest of the shipwreck, including wood, coal, and gold surfaces as well as patches of the adjacent sediment ooze. Wooden portions of the shipwreck buried in anoxic layers of sediment (>5 cm deep) were blackened but better preserved. A debris field surrounding the hull of the shipwreck contained many, well-preserved artifacts (e.g., leather-bound passenger trunks and ceramics) that were less susceptible to iron-oxide deposition.

Since the site was at least 1,000 m shallower than the turbid nepheloid layer, water clarity was exceptionally clear and tranquil most of the time. A gentle southward-flowing current continually flushed the site and maintained high dissolved oxygen levels. Although long-term sedimentation rates were low, a few benthic storms were experienced that eroded and transported considerable quantities of the sediment ooze upon which the shipwreck rested.

A seemingly paradoxical situation existed at this place in the deep sea—high animal diversity in an environment thought to be stable and energy poor. In reality, the site was a dynamic ecosystem fueled by the presence of the shipwreck and the attendant alterations of seabed processes. Features of the shipwreck, particularly hard, elevated surfaces and the clear, oxygen-rich environment provided favorable habitats which fostered proliferation of benthic invertebrates and bathypelagic fishes. The diversity and numbers of the macrofauna and megafauna were one to two orders of magnitude higher than on the surrounding sediment ooze.

Most of the major, deep-ocean taxonomic groups were observed on the site, including at least ten undescribed species (hexactinellid sponges, gorgonian coral, antipatharian coral, actinostolid anemone, pholadid bivalves, incirrate octopus, geryonid crab, calloporid bryozoa, and chiridotid sea cucumber). Most groups appeared to be adapted for feeding on suspended organic debris or organic material in the sediment. At more than 1,000 m below the penetration of sunlight, many of the animals lacked pigmented eyes and sight feeding was not observed. The initial colonization of the shipwreck may have been by the larvae of pholadid bivalves that bored into the ship's wood. This infestation, coupled with colonization by the larvae of hard-substrate, sessile animals, led to a rich biological community. The pholadid population appeared to have utilized the ship's wood to a maximum extent, reducing it to riddled timbers. This stage may have been reached at some time in the past, for no living borers were found in wood samples or observed in video images. Thus, degradation of the wood must have slowed since that time and the shipwreck may have reached a more stable condition.

Cultural artifacts recovered from the shipwreck included several hundred objects that were either part of the ship or were brought on board by the passengers and crew. Ceramic and glassware items were minimally altered whereas metal and wood objects were the most degraded, with the exception of chemically stable gold and coal. Two passenger trunks yielded hundreds of surprisingly well-preserved artifacts, including textiles and paper. Reducing conditions in these trunks may have contributed to preservation of these materials. Cabin articles provided a glimpse of shipboard life in the 1850s whereas trunk artifacts gave considerable insight into the personal lives of east-bound passengers. Numismatic artifacts, in the form of gold coins and specie bars, yielded an unprecedented view of government and private gold minting and ingot manufacturing during the California Gold Rush period.

The deep ocean, like all other barrier frontiers throughout history, has remained impenetrable by traditional approaches. Discoveries in the deep ocean, particularly the systematic penetration of the deep-ocean frontier, awaited the invention of new technologies that would enable proficient and productive work on the seabed. Until now it has been impossible to perform complicated tasks on the deep-ocean floor except imaging and gross sampling. The research submersible *Nemo* has extended our ability to conduct scientific inquiry in an alien environment. The advanced design features of *Nemo* have provided science with its first working presence in the deep ocean.

This project demonstrated that a diverse program of scientific investigations can be successfully integrated into a deep-ocean recovery operation. The research findings and technological developments of both the recovery operation and the scientific program proved beneficial to one another. By approaching the shipwreck as an isolated ecosystem, it was possible to focus research activities on the interrelated processes in operation in the deep ocean. Unraveling the thirteen decades of transformation processes at the SS *Central America* site has provided valuable data for predicting the fate of other cultural deposits on the seafloor.

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Participants in the Adjunct Science and Education Program
SS *Central America* Project

Dr. D. K. Abbass, National Maritime Historical Society, Newport, RI – undersea archaeology

Dr. R. Tucker Abbott, American Malacologists, Inc., Melbourne, FL – pteropods

Ms. Cynthia G. Ahearn, National Museum of Natural History, Smithsonian Institution – echinoderms

Mr. Bryan Anderson, Columbus-America Discovery Group – sampling devices; engineering

Rear Admiral Christian Andreasen, International Hydrographic Bureau, Monaco – bathymetric data

Mr. Christopher R. Baker, Columbus-America Discovery Group – sampling devices; engineering

Mr. William Ballenger, Chicago Maritime Historical Society & Museum – steamship construction

Dr. Jerry L. Barnard (deceased), National Museum of Natural History, Smithsonian Institution – amphipods

Dr. Frederick M. Bayer, National Museum of Natural History, Smithsonian Institution – gorgonian corals

Dr. Keith Bedford, Civil Engineering, The Ohio State University – ocean & sediment dynamics

Dr. Tim M. Berra, Zoology, The Ohio State University – deep-ocean elasmobranchs

Mr. Henry T. Bishop, Steamship Historical Society of America, Providence, RI – steamship construction

Ms. Jennifer Bour, Columbus-America Discovery Group – communications

Dr. Thomas E. Bowman, National Museum of Natural History, Smithsonian Institution – isopods and barnacles

Dr. Charles W. Boylen, Biology, Rensselaer Polytechnic Institution – deep-sea benthic communities

Ms. Laura Brown, Steamship Historical Soc. America, University of Baltimore – history of SS *Central America*

Ms. Debra L. Burley, Columbus-America Discovery Group – artifact database

Mr. Wm. B. Burlingham, III, Columbus-America Discovery Group – Captain, R/V *Arctic Discoverer*, meteorology

Dr. David R. Bush, Archaeological Laboratory, Case Western Reserve University – archaeology

Mr. Milton T. Butterworth Jr., Columbus-America Discovery Group – deep-sea and artifact photographs

Mr. Milton T. Butterworth III, Columbus-America Discovery Group – photograph database

Dr. Martin A. Buzas, National Museum of Natural History, Smithsonian Institution – benthic foraminifera

Dr. Stephen D. Cairns, National Museum of Natural History, Smithsonian Institution – hard corals

Dr. John M. Cassady, College of Pharmacy, The Ohio State University – pharmacological screening of sponges

Mr. James Cheevers, The Museum, U.S. Naval Academy – history of SS *Central America* and Cdr. Herndon

Mr. Dustin D. Chivers, Invertebrate Zoology, California Academy of Sciences – marine invertebrates

Dr. Eugenie Clark, Zoology, University of Maryland – deep-sea sharks and fish communities

Mr. Thomas Clark, South Carolina Educational Television, Columbia, SC – marine science education

Mr. Richard Clerke, WOSU-TV, The Ohio State University – marine science education; video production

Mr. Timothy E. Coffer, Nat. Museum of Natural History, Smithsonian Institution – field collection; cnidarians

Dr. Daniel M. Cohen, Life Sciences, Natural History Museum of Los Angeles County – deep-sea fishes

Dr. Charles F. Cole, Natural Resources, The Ohio State University – deep-sea fishes; fisheries

Ms. Judith Conrad, Columbus-America Discovery Group – history of SS *Central America*; artifact database

Dr. Clayton Cook, Harbor Branch Oceanographic Institution – marine biology

Dr. Susan B. Cook, Harbor Branch Oceanographic Institution – marine science education

Dr. Gary Cygan, Mineralogy, U.S. Geological Survey – mineralogy of gold nuggets

Dr. William S. Dancey, Anthropology, The Ohio State University – archaeology

Dr. Paul R. Dando, Geochemistry, Marine Biological Assoc., Plymouth, England – deep-sea methane; sediments

Mr. Richard M. DeAngelis, National Oceanographic Data Center, NOAA – hurricane meteorology

Dr. Wallentina DeWeerdt, National Museum of Natural History, Smithsonian Institution – deep-sea sponges

Dr. George Disterdick, Veterinary Hospital, The Ohio State University – x-ray analysis of wood from SS *Central America*

Dr. Edwin L. Dunbaugh, Marine Engineering, Webb Institute of Naval Architecture – steamship construction

Dr. K. O. Emery, Geology, Woods Hole Oceanographic Institution – geological oceanography of North Atlantic

Dr. William N. Eschmeyer, Ichthyology, California Academy of Sciences – deep-sea fishes

Mr. Robert D. Evans, Columbus-America Discovery Group – deep-sea geology; archaeology

Ms. Kitty Farnell, Lexington County Schools, Ballentine, SC – marine science education

Dr. Kristian Fauchald, National Museum of Natural History, Smithsonian Institution – polychaetes

Dr. D. John Faulkner, Scripps Institution of Oceanography, UCSD – biochemistry of deep-sea sponges

Dr. Daphne Gail Fautin, Systematics & Ecology, University of Kansas – sea anemones

Dr. Gary L. Floyd, Plant Biology, The Ohio State University – diatoms

Dr. D. W. Foreman, Oral Biology, The Ohio State University – fiber x-ray diffraction analysis

Dr. Jane L. Forsyth, Geology, Bowling Green State University – manuscript review

Dr. Rosanne Fortner, Natural Resources & Science Education, The Ohio State University – marine science education

Ms. Katherine M. Fritsch, Columbus-America Discovery Group – artifact conservation

Dr. Brian Gibeson, Education, California Academy of Sciences – marine mammals

Dr. Ronald W. Gilmer, Marine Biology, Harbor Branch Oceanographic Institution – pteropods

Mr. Donald J. Hackman, Battelle Memorial Institute – nineteenth-century steam engines; benthic samplers

Ms. Suzanne M. Hartley, Clyde High School, Clyde, OH – marine science education

Dr. Willard D. Hartman, Peabody Museum, Yale University – hexactinellid sponges

Ms. Joyce Hayward, York School, Bellevue, OH – marine science education

Dr. Barbara Hecker, Lamont-Doherty Earth Observatory, Columbia University – marine biology

Dr. Charles E. Herdendorf, Geological Sciences & Zoology, The Ohio State University – oceanography; archaeology
Ms. Ricki C. Herdendorf, EcoSphere Associates, Huron, OH – manuscript review
Dr. David K. Ho, College of Pharmacy, The Ohio State University – pharmacological screening of sponge tissue
Mr. Robert E. Hodgdon, Columbus-America Discovery Group – logistics
Dr. W. Duane Hope, National Museum of Natural History, Smithsonian Institution – marine nematology
Dr. Frederick Hopkins, Literature, University of Baltimore – maritime history & undersea archaeology
Dr. Terry M. Hume, Oceanography, New Zealand National Institute of Water & Atmospheric Research – sediment
Dr. Tomio Iwamoto, Ichthyology, California Academy of Sciences – deep-sea fishes
Dr. Kathryn A. Jakes, Textiles & Clothing, The Ohio State University – textile preservation; archaeology
Mr. Edward Jaworski, Webb Institute of Naval Architecture – materials science
Dr. James Jenkins, Corrosion Engineering, U.S. Navy Civil Engineering Laboratory – deep-sea corrosion
Dr. James P. Karwowski, Microbiology, Abbott Laboratories, Abbott Park, IL – microorganisms
Mr. Charles Kleibacker, Historic Costume & Textiles, The Ohio State University – garment artifacts
Dr. Jan J. Kohlmeyer, Marine Sciences, University of North Carolina – marine fungi
Dr. Lawrence A. Krissek, Geological Sciences, The Ohio State University – deep-sea sediments
Mr. James Lamb, Coins & Bank Notes, Christie, Manson & Wood International, New York – numismatics
Dr. John Loret, Long Island Science Museum, Manhasset, NY – marine biology
Mr. F. Michael Lorz, Lorz Communications, Inc., Columbus, OH – marine science education; communications
Dr. Brian E. Luckhurst, Fisheries, Bermuda Department of Agriculture, Fisheries & Parks – deep-sea crustaceans
Dr. Raymond B. Manning, National Museum of Natural History, Smithsonian Institution – deep-sea crabs
Dr. William Mattox, Ohio Department of Natural Resources, Columbus, OH – Greenland sharks; fisheries
Mr. Lance McAlfee, Columbus-America Discovery Group – logistics
Dr. Anna M. McCann, Archaeology, Williams College – undersea archaeology
Dr. Samuel B. McDowell, Biological Sciences, Rutgers University – deep-sea fishes
Dr. Dorte Mehl, Inst. f. Palaeontologie, Freie Universtat Berlin, Germany – glass sponges
Dr. Frederick P. Mertz, Microbiology, Lilly Research Laboratories, Indianapolis, IN – actinomycetes
Dr. Charles G. Messing, Oceanographic Center, Nova University – crinoids
Dr. Glyn Meyrick, Materials Science and Engineering, The Ohio State University – metals analysis
Dr. Cynthia Miller, Microbiology, The Ohio State University – microbial analysis
Mr. John E. Miller, Marine Biology, Harbor Branch Oceanographic Institution – brisingid starfish
Mr. Michael Milosh, Columbus-America Discovery Group – submersible pilot; mechanical engineering
Mr. John C. Mitchell, Geological Sciences, The Ohio State University – fiber SEM analysis
Mr. Mark Monaco, National Ocean Survey, Ocean Assessment, NOAA – habitat assessment; fisheries
Mr. John Moore, Sound Ocean Systems, Seattle, WA – submersible pilot; mechanical engineering
Dr. Lee Ann Newsom, Ethnobiology, Florida Museum of Natural History – wood analysis SS *Central America*
Mr. Tim Noonan, Columbus-America Discovery Group – maritime history; communications
Dr. Scott Nixon, Oceanography, University of Rhode Island – community interactions
Dr. Dennis Opresko, Biology, Oak Ridge National Laboratory, Oak Ridge, TN – deep-sea antipatharians
Dr. James K. Orzech, Ocean Science Research Institute, San Diego, CA – undersea archaeology
Dr. Wendell K. Patton, Zoology, Ohio Wesleyan University – deep-sea benthic communities
Dr. David L. Pawson, National Museum of Natural History, Smithsonian Institution – echinoderms
Ms. Sue W. Pfeiffer, Herndon Intermediate School, Herndon, VA – marine science education
Dr. Robert Pfister, Microbiology, The Ohio State University – marine microbiology
Mr. Samuel O. Raymond, Benthos, Inc., North Falmouth, MA – marine technology; deep-sea rusticles
Dr. Henry M. Reiswig, Redpath Museum, McGill University, Montreal, Quebec, Canada – deep-sea sponges
Dr. Jeffrey M. Reutter, Sea Grant, The Ohio State University – marine science education
Dr. Mary E. Rice, Smithsonian Marine Station, Link Port, FL – polychaetes
Ms. Jane E. Rindsberg, Columbus-America Discovery Group – admiralty law
Dr. Eleanora I. Robbins, U.S. Geological Survey – microbiology; formation of rusticles
Mr. Richard T. Robol, Columbus-America Discovery Group – admiralty law
Dr. Clyde F. E. Roper, National Museum of Natural History, Smithsonian Institution – cephalopods
Dr. Richard H. Rosenblatt, Scripps Institution of Oceanography, UCSD – deep-sea fishes
Dr. David A. Ross, Geology & Geophysics, Woods Hole Oceanographic Institution – geological oceanography
Dr. Gilbert I. Rowe, Oceanography, Texas A & M University – deep-sea sediment imprints
Ms. Linda M. Saup, Columbus-America Discovery Group – artifact database
Mr. John B. Schatz, Columbus-America Discovery Group – communications; marine science education
Mr. Alan Scott, Columbus-America Discovery Group – navigation; image processing
Ms. Pamela J. Sears, Maritime Center at Norwalk, Norwalk, CT – marine science education
Mr. Scott A. Shade, Columbus-America Discovery Group – deep-ocean sampling; logistics
Dr. Andrew N. Shepard, Undersea Research, University of North Carolina at Wilmington – oceanography; logistics
Dr. Lucy R. Sibley (deceased), Textiles & Clothing, The Ohio State University – textile history
Dr. John McNeill Sieburth, Oceanography & Microbiology, University of Rhode Island – diatom photomicrographs
Dr. Susan Smialowska, Metallurgical Engineering, The Ohio State University – metal corrosion
Dr. C. Lavett Smith, Ichthyology, American Museum of Natural History, New York – deep-sea fishes
Ms. Susan L. Snyder, Jones Middle School, Upper Arlington, OH – marine science education
Dr. Alan Southward, Marine Biological Assoc., Plymouth, England – deep-sea photography
Dr. Eva Southward, Marine Biological Assoc., Plymouth, England – deep-sea invertebrates
Dr. George R. St. Pierre, Materials Science and Engineering, The Ohio State University – iron corrosion
Mr. Peter Stanford, National Maritime Historical Society, Peekskill, NY – maritime history
Dr. David H. Stansbery, Zoology & Museum of Biodiversity, The Ohio State University – deep-sea molluscs
Ms. Cynthia Stong, Marine Sciences, Bowling Green State University – manuscript review
Dr. Lawrence D. Stone, Mathematics, Metron, Inc., Reston, VA – mathematical search theory
Dr. Ronald L. Stuckey, Plant Biology, The Ohio State University – aquatic plants; biogeography
Mr. Robert F. Sumrall, Ship Models, U.S. Naval Academy Museum – design of SS *Central America*
Mr. Michael Sweeney, National Museum of Natural History, Smithsonian Institution – cephalopods
Mr. William duBarry Thomas, Naval Architecture, Convent Station, NJ – construction of SS *Central America*
Mr. Thomas G. Thompson, Columbus-America Discovery Group – deep-ocean engineering; maritime history
Dr. Ronald B. Toll, Biology, Wesleyan College, Macon, GA – deep-sea experiments; cephalopods
Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University – wood-boring molluscs
Ms. Julie Vanover, Columbus-America Discovery Group – manuscript review; communications

Dr. Michael Vecchione, National Marine Fisheries Service, NOAA – cephalopods; pteropods
Dr. Janet Voight, Molluscs, Field Museum of Natural History, Chicago, IL – cephalopods
Dr. Charles W. Walker, Zoology, University of New Hampshire – echinoderms
Dr. Thomas Waters, Zoology, The Ohio State University – deep-sea molluscs
Dr. W. Jeffrey Welsh, History, Bowling Green State University – history of Gold Rush period
Mr. Howard White, Lima City Schools, Lima, OH – marine science education
Ms. Debra A. Willaman, Columbus-America Discovery Group – artifact database; logistics
Dr. Austin B. Williams, National Marine Fisheries Service, NOAA – galatheid crabs
Mr. James Wilson (deceased), Steamship Historical Society of Am., Providence, RI – steamship engineworks
Dr. Judith E. Winston, Research & Collections, Virginia Museum of Natural History – bryozoans
Ms. Mary J. Wright, Interactive Multimedia, The Discovery Channel, Bethesda, MD – marine science education
Mr. Joseph W. Zarzynski, Bateaux Below, Inc., Lake George, NY – marine education; archaeology
Mr. Zachary Zevitas, Education Science Network, Boston, MA – marine science education

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APPENDIX A

Taxonomic listing of organisms from SS Central America *shipwreck, Blake Ridge, North Atlantic Ocean (Lat 32° N, Long 77° W; 2,200 m deep).*

	Organism	Identifier/Reference	Specimen No. [Location]
	DIVISION BACTERIA		
	Class Schizomycetes		
	Order Chlamydobacteriales (sheath-forming bacteria)		
	Family Chlamydobacteriaceae	Krueger & Johansson, 1959, p. 95	
1.	*Leptothrix* spp.	Eleanora I. Robbins - USGS	Photomicrograph [USGS]
	DIVISION CHRYSOPHYTA (golden-brown algae)		
	Class Chrysophyceae		
	Order Coccosphaerales (coccolithophores)		
	Family Pontosphaeraceae		
2.	*Emiliania huxleyi*	Eleanora I. Robbins - USGS	Photomicrograph [USGS]
	Class Bacillariophyceae (diatoms)		
3.	Order Pennales (pennate diatoms)	John M. Sieburth - Univ Rhode Island Gary L. Floyd - Ohio State Univ	Photomicrograph [CA]
	DIVISION PHAEOPHYTA (brown algae)		
	Class Phaeophyceae		
	Order Fucales		
	Family Sargassaceae (sargassum weed)		
4.	*Sargassum fluitans* Boergesen	Littler et al., 1989, p. 124	BR-159 [MBD]
5.	*Sargassum natans* (Linnaeus)	Littler et al., 1989, p. 122	BR-135, -159, -176, -179 [MBD]
	DIVISION SPERMATOPHYTA (seed plants)		
	Class Pinatae (conifers)		
	Family Pinaceae (pines)		
	Section Diplozylon (southern hard pines)		
6.	*Pinus palustris* Miller (longleaf pine)	Lee A. Newsom - Florida MNH	BR-191 [FMNH]
	PHYLUM PROTOZOA		
	Subphylum Sarcodina		
	Class Granuloreticulosa		
	Order Foraminifera		
	Superfamily Ammodiscoidea (benthic forams)		
	Family Ammodiscidae		
7.	*Ammodiscus* sp.	Loeblich & Tappen, 1964, p. C210	BR-300 [MBD]
	Family Astrorhizidae		
8.	*Rhabdammina abyssorum* Carpenter	Loeblich & Tappen, 1964, p. C185	BR-300 [MBD]
	Superfamily Milioloidea (benthic forams)		
	Family Soritidae (ramshorns)		
9.	*Peneroplis* sp.	Loeblich & Tappen, 1964, p. C482 Tappen & Loeblich, 1982, pl. 48	BR-300 [MBD]
	Superfamily Robertinoidea (benthic forams)		
	Family Epistominidae		
10.	*Hoeglundina elegans* (d'Orbigny)	Loeblich & Tappen, 1964, p. C775	BR-300 [MBD]
	Superfamily Buliminoidea (benthic forams)		
	Family Buliminidae		
11.	*Bulimina aculeata* d'Orbigny	Loeblich & Tappen, 1964, p. C559 Cushman, 1922, pl. 22	BR-300 [MBD]
	Superfamily Globigerinoidea (planktonic forams)		
	Family Globigerinidae		
12.	*Globigerina bulloides* d'Orbigny	Loeblich & Tappen, 1964, p. C669	BR-300 [MBD]
13.	*Globigerina* spp.	Bé, Vilks & Lott, 1971, p. 39	BR-300 [MBD]
14.	*Orbulina universa* d'Orbigny	Loeblich & Tappen, 1964, p. C675	BR-300 [MBD]
	Family Globorotaliidae		
15.	*Globorotalia menardii* (d'Orbigny)	Loeblich & Tappen, 1964, p. C667 Bé, Vilks & Lott, 1971, p. 41	BR-300 [MBD]

APPENDIX A (CONTINUED)

Organism	Identifier/Reference	Specimen No. [Location]
Class Phaeodaria (=Radiolaria)		
Order Phaeocalpida		
Superfamily Challengeriicae		
Family Circoporidae		
16. *Circostephanus coronarius* Haeckel, 1887	Campbell & Moore, 1954, p. D154	BR-112 [MBD]
PHYLUM PORIFERA (sponges)		
Class Demospongiae (horny sponges)		
Order Axinellida		
Family Axinellidae		
17. *Phakellia* sp.	Henry M. Reiswig - McGill Univ	HMR-91-8-28.6
Order Haplosclerida		
Family Haliclonidae		
18. *Haliclona* sp.	Henry M. Reiswig - McGill Univ	HMR-91-8-28.4
Order Poecilosclerida		
Family Esperiopsidae		
19. genus ?	Henry M. Reiswig - McGill Univ	HMR-91-8-28.1
Family Hymedesmiidae		
20. *Hymedesmia* sp.	Henry M. Reiswig - McGill Univ	HMR-91-8-28.17
Class Hexactinellida (glass sponges)		
Order Hexactinosida		
Suborder Clavularia		
Family Farreidae		
21. *Farrea occa* Bowerbank, 1862	Henry M. Reiswig - McGill Univ	Photograph [CA]
22. *Farrea* sp. (feather form)	Henry M. Reiswig - McGill Univ	Photograph [CA]
23. *Farrea* (new species)	Henry M. Reiswig - McGill Univ	HMR-90-10-9.3; BR-131, -162 [MBD]
Suborder Scopularia		
Family Euretidae		
24. *Calyptorete* sp.	Henry M. Reiswig - McGill Univ	Photograph [CA]
25. *Conorete erectum* (Schulze, 1899)	Henry M. Reiswig - McGill Univ	Photograph [CA]
26. *Dactylocalyx pumiceus* Stutchbury, 1841	Wallentina DeWeerdt - USNM	Photograph [CA]
27. *Eurete* sp.	Henry M. Reiswig - McGill Univ	HMR-90-10-10.2a
28. *Lefroyella decora* Thomson, 1877	Henry M. Reiswig - McGill Univ	Photograph [CA]
Family Aulocalycidae		
29. *Rhabdodictym delicatum* (Schmidt, 1880)	Henry M. Reiswig - McGill Univ	HMR-90-10-9.2a&b
30. *Rhabdodictym* sp.	Henry M. Reiswig - McGill Univ	HMR-91-8-28.5; BR-182, -189 [MBD]
31. new genus & species	Henry M. Reiswig - McGill Univ	HMR-91-8-7.1
Family Craticulariidae		
32. *Chonelasma choanoides* (Schulze & Kirkpatrick, 1910)	Henry M. Reiswig - McGill Univ	HMR-90-10.9.1
Family Aphrocallistidae		
33. *Aphrocallistes beatrix* Gray, 1858	Henry M. Reiswig - McGill Univ	Photograph [CA]
Order Lyssacinosida		
Family Leucopsacadidae		
34. *Caulocalyx tenera* Schulze, 1886	Henry M. Reiswig - McGill Univ	Photograph [CA]
Family Caulophacidae		
35. *Caulophacus agassizi* Schulze, 1899	Henry M. Reiswig - McGill Univ	Photograph [CA]
36. *Caulophacus arcticus* (Hansen, 1885)	Henry M. Reiswig - McGill Univ	Photograph [CA]
37. *Sympagella nux* Schmidt, 1870	Henry M. Reiswig - McGill Univ	Photograph [CA]
Family Euplectellidae		
38. *Euplectella jovis* Schmidt, 1880	Henry M. Reiswig - McGill Univ	Photograph [CA]
Family Rossellidae		
39. *Rossella* spp.	Henry M. Reiswig - McGill Univ	HMR-91-8-28.11; Photograph [CA]

APPENDIX A (CONTINUED)

	Organism	Identifier/Reference	Specimen No. [Location]
	PHYLUM CNIDARIA (=COELENTERATA)		
	Class Hydrozoa		
	Order Hydroida (polypoid hydrozoans)		
	Suborder Anthomedusae		
	Family Pennariidae (pinnate hydroid)		
40.	*Pennaria* sp. (?)	Barnes, 1987, p. 101	Photograph [CA]
	Family Tubulariidae		
41.	*Acryptolaria conferta* (Allman)	Timothy E. Coffer - USNM	BR-190, -201 [MBD]
42.	*Tubularia* sp.	Timothy E. Coffer - USNM	Photograph [CA]
	Order Siphonophora		
	Suborder Physonectae		
	Family Agalmidae	Timothy E. Coffer - USNM	
43.	*Pterophysa grandis* Fewkes	Agassiz, 1888, vol. 1, p. 184	BR-142 [MBD]
	Class Scyphozoa		
	Order Coronatae		
	Family Nausithoidae		
44.	*Stephanoscyphus* (=*Nausithoe*) sp.	Timothy E. Coffer - USNM	BR-115, -208 [MBD]
	Family Atollidae		
45.	*Atolla* sp.	Marshall, 1979, p. 87 Agassiz, 1888, vol. 2, p. 133	Photograph [CA]
	Class Anthozoa		
	Subclass Alcyonaria (=Octocorallia)		
	Order Alcyonacea (soft corals)		
	Family Alcyoniidae		
46.	*Anthomastus agassizi* Verrill	Barbara Hecker - Columbia Univ	Photograph [CA]
	Family Nephtheidae		
47.	*Neospongodes agassizi* Deichmann, 1936	Frederick M. Bayer - USNM	Photograph [CA]
	Order Gorgonacea (horny or gorgonian corals; sea fans)		
	Family Chrysogorgiidae		
48.	*Chrysogorgia* (new species)	Frederick M. Bayer - USNM	USNM Cat. No. 91934 & 91935; BR-127, -128, -234 [MBD]
	Family Primnoidae		
49.	*Thouarella crenulata* (Kukenthal)	Frederick M. Bayer - USNM	Photograph [CA]
	Family Paragorgiidae		
50.	*Paragorgia johnsoni* Gray, 1869	Frederick M. Bayer - USNM	Photograph [CA]
	Order Pennatulacea (sea pens; sea pansies)		
	Family Umbellulidae		
51.	*Umbellula* sp. (?)	Barnes, 1987, p. 137	Photograph [CA]
	Family Pennatulidae (sea pens)		
52.	*Pennatula* sp. (?)	Menzies et al., 1973, p. 116	Photograph [CA]
	Subclass Zoantharia (=Hexacorallia)		
	Order Actiniaria (sea anemones)		
	Family Actinernidae		
53.	*Actinernus michaelsarsi* Carlgren, 1918	Daphne G. Fautin - Univ Kansas	USNM Cat. No. 88367
54.	*Actinernus nobilis* (Verrill, 1879)	Barbara Hecker - Columbia Univ	Photograph [CA]
	Family Actinoscyphiidae		
55.	*Actinoscyphia* sp.	Daphne G. Fautin - Univ Kansas	Photograph [CA]
	Family Actinostolidae		
56.	*Paractinostola* (new species ?)	Daphne G. Fautin - Univ Kansas	BR-169 [MBD]
57.	*Actinauge* sp.	Barbara Hecker - Columbia Univ	Photograph [CA]

APPENDIX A (CONTINUED)

Organism	Identifier/Reference	Specimen No. [Location]
Family Hormathiidae		
58. *Chondrophellia coronata* (Verrill, 1883)	Daphne G. Fautin - Univ Kansas	USNM Cat. No. 88366
59. *Paracalliactis* sp.	Shick, 1991	Photograph [CA]
Order Scleractinia (stony corals)		
Family Caryophylliidae		
60. *Desmophyllum cristagalli* Milne-Edwards & Haime, 1848	Stephen D. Cairns - USNM	USNM Cat. No. 91933; BR-184, BR-188 [MBD]; BR-302 [WC]
Order Antipatharia (black corals)		
Family Antipathidae		
61. *Hexapathes* (new species)	Dennis Opresko - Oak Ridge NL	BR-301 [ORNL]
PHYLUM CTENOPHORA (comb jellies)		
Class Tentaculata		
Order Lobata		
Family Bolinopsidae		
62. *Mnemiopsis* sp.	Henry M. Reiswig - McGill Univ	Photograph [CA]
Family Bathocyroidae		
63. *Bathocyroe fosteri* Madin & Harbison, 1978	Michael Vecchione - NMFS	Photograph [CA]
PHYLUM NEMATODA (=NEMATA) (roundworms)		
64. Class Adenophorea (?)	Maggenti, 1982, p. 880	BR-258 [MBD]
PHYLUM SIPUNCULA (peanut worms)		
Family Golfingiidae		
65. *Golfingia margaritacea* (Sars)	Stephen & Edmonds, 1972, p. 98	BR-141 [MBD]
PHYLUM MOLLUSCA		
Class Bivalvia (=Pelecypoda)		
Subclass Pteriomorphia		
Order Mytiloida		
Family Mytilidae		
66. *Amygdalum* sp.	Ruth D. Turner - Harvard Univ	BR-303 [MCZ]
Subclass Heterodonta		
Order Veneroida		
Family Veneridae (Venus clams)		
67. *Dosinia* sp.	Ruth D. Turner - Harvard Univ	BR-304 [MCZ]
Order Myoida (thin-shelled burrowers)		
Family Pholadidae (burrowing clams)		
Subfamily Xylophagainae (wood borers)		
68. *Xylophaga abyssorum* Dall, 1886	Ruth D. Turner - Harvard Univ	Photograph [CA]
69. *Xyloredo nooi* Turner, 1972	Ruth D. Turner - Harvard Univ	BR-305 [MCZ]
70. & 71. *Xyloredo* (new species a & b)	Ruth D. Turner - Harvard Univ	BR-133, -222, -223, -257 [MCZ]
Family Teredinidae (shipworms)		
72. *Psiloteredo healdi* (Bartsch, 1931)	Ruth D. Turner - Harvard Univ	BR-306 [MCZ]
73. *Psiloteredo megotara* (Hanley, 1848)	Ruth D. Turner - Harvard Univ	BR-307 [MCZ]
Subclass Anomalodesmata (=Septibranchia)		
Order Pholadomyoida		
Family Poromyidae (deep-sea mussels)		
74. *Poromya neaeroides* Seguenza, 1876	Ronald B. Toll - Wesleyan College	BR-308 [WC]
Family Cuspidariidae		
75. *Cuspidaria obesa* (Lovén, 1846)	Ruth D. Turner - Harvard Univ	BR-309 [MCZ]
Class Gastropoda (snails)		
Subclass Prosobranchia		
Order Archaeogastropoda		
Superfamily Trochacea		
Family Trochidae (top shells)		
76. *Solariella infundibulum* (Watson, 1879)	Abbott, 1974, p. 41	BR-310 [MCZ]

APPENDIX A (CONTINUED)

Organism	Identifier/Reference	Specimen No. [Location]
Order Mesogastropoda		
Superfamily Epitoniacea		
Family Janthinidae (purple sea-snails)		
77. *Janthina exigua* Lamarck, 1816 (dwarf purple)	Abbott, 1974, p. 113	BR-21, -81 [MBD]
Superfamily Heteropoda		
Family Atlantidae		
78. *Atlanta peroni* Lesueur, 1817	Abbott, 1974, p. 133	BR-89, -90 [MBD]
Family Carinariidae		
79. *Carinaria lamarcki* Péron & Lesueur, 1810	Abbott, 1974, p. 134	BR-80 [MBD]
Order Neogastropoda		
Superfamily Conacea		
Family Turridae (turret shells)		
80. *Cymatosyrinx centimata* (Dall, 1889)	Ruth D. Turner - Harvard Univ	BR-311 [MCZ]
81. *Gymnobela* sp.	Abbott, 1974, p. 289	BR-312 [MCZ]
82. *Inodrillia* cf. *dalli* (Verrill & Smith, 1882)	Ruth D. Turner - Harvard Univ	BR-313 [MCZ]
83. *Leucosyrinx* sp.	Abbott, 1974, p. 263	BR-314 [MCZ]
84. *Pleurotomella bairdii* Verrill & Smith, 1884	Ruth D. Turner - Harvard Univ	BR-315 [MCZ]
85. *Pleurotomella curta* (Verrill, 1884)	Ruth D. Turner - Harvard Univ	BR-316 [MCZ]
86. *Pleurotomella emertonii* Verrill & Smith, 1884	Ruth D. Turner - Harvard Univ	BR-317 [MCZ]
87. *Pleurotomella jefferysii* Verrill, 1885	Ruth D. Turner - Harvard Univ	BR-318 [MCZ]
88. *Pleurotomella packardii* Verrill, 1873	Ruth D. Turner - Harvard Univ	BR-319 [MCZ]
Subclass Opisthobranchia		
Order Cephalaspidea		
Family Cylichnidae		
89. *Cylichna verrillii* Dall, 1889 (Verrill's bubble)	Abbott, 1974, p. 315	BR-22 [MBD]
Family Bullidae (bubble shells)		
90. *Bulla* sp.	Ruth D. Turner - Harvard Univ	BR-320 [MCZ]
Order Thecosomata (pteropods)		
Suborder Euthecosomata (shelled pteropods)		
Family Limacinidae	C. E. Herdendorf - Ohio State Univ	
91. *Limacina bulimoides* (d'Orbigny, 1836) (bulimoid pteropod)		BR-85 [MBD]
92. *Limacina inflata* (d'Orbigny, 1836) (planorbid pteropod)		BR-86 [MBD]
93. *Limacina lesueuri* (d'Orbigny, 1836) (Lesueur's pteropod)		BR-87 [MBD]
94. *Limacina trochiformis* (d'Orbigny, 1836) (trochiform pteropod)		BR-88 [MBD]
95. *Cavolinia gibbosa* (d'Orbigny, 1836) (humpback cavoline)		BR-91, -92 [MBD]
96. *Cavolinia inflexa* (Lesueur, 1813) (inflexed cavoline)		BR-95 [MBD]
97. *Cavolinia longirostris* (Blainville, 1821) (long-snout cavoline)		BR-94 [MBD]
98. *Cavolinia tridentata* (Niebuhr, 1775) (three-toothed cavoline)		BR-96, -181, -194 [MBD]
99. *Cavolinia uncinata* (Rang, 1829) (uncinate cavoline)		BR-97, -98 [MBD]
100. *Clio pyramidata* Linnaeus, 1767 (pyramid clio)		BR-101, -102, -205 [MBD]
101. *Clio cuspidata* (Bosc, 1802) (cuspidate clio)		BR-99 [MBD]
102. *Clio recurva* (Children, 1823) (wavy clio)		BR-103 [MBD]
103. *Creseis acicula* (Rang, 1828) (straight needle-pteropod)		BR-104 [MBD]
104. *Creseis virgula* (Rang, 1828) (curved needle-pteropod)		BR-105 [MBD]
105. *Cuvierina* (=*Herse*) *columnella* (Rang, 1827) (cigar pteropod)		BR-106, -107 [MBD]
106. *Diacria trispinosa* (Blainville, 1821) (three-spined cavoline)		BR-109 [MBD]
107. *Diacria quadridentata* (Blainville, 1821) (four-toothed cavoline)		BR-108 [MBD]
108. *Hyalocylis striata* (Rang, 1828) (striate clio)		BR-110 [MBD]
109. *Styliola subula* (Quoy & Gaimard, 1827) (keeled clio)		BR-111 [MBD]
Suborder Pseudothecosomata		
Family Peraclididae		
110. *Peraclis reticulata* (d'Orbigny, 1836)	C. E. Herdendorf - Ohio State Univ	BR-82 [MBD]
111. *Peraclis* spp.	Ronald B. Toll - Wesleyan College	BR-326 [WC]

APPENDIX A (CONTINUED)

Organism	Identifier/Reference	Specimen No. [Location]
Class Cephalopoda		
Subclass Coleoidea		
Order Octopoda (octopods)		
Suborder Incirrata (finless octopods)		
Family Octopodidae		
Subfamily Bathypolypodinae		
112. *Benthoctopus oregonae* (Toll, 1981)	Janet Voight - Field Mus NH	Photograph [CA]
113. *Benthoctopus* (new species)	Clyde F. E. Roper - USNM	Photograph [CA]
	Michael Vecchione - NMFS	Photograph [CA]
114. *Pteroctopus tetracirrhus* (Delle Chiage, 1830)	Ronald B. Toll - Wesleyan College	Photograph [CA]
Family Argonautidae (paper nautiluses)		
115. *Argonauta argo* Linnaeus, 1758 (paper nautilus)	C. E. Herdendorf - Ohio State Univ	BR-137 [MBD]
PHYLUM ANNELIDA (segmented worms)		
Class Polychaeta (bristle worms)		
Subclass Errantia		
Order Phyllodocida		
Family Nereidae (clam worms)		
116. *Nereis* sp.	Kristian Fauchald - USNM	Photograph [CA]
Family Polynoidae (scale worms)		
117. *Eulagisca* sp.	Kristian Fauchald - USNM	BR-186 [MBD]
Order Eunicida		
Family Onuphidae (quillworms)		
118. *Hyalinoecia artifex* Verrill	Kristian Fauchald - USNM	BR-141, -144, -215 [MBD]
Subclass Sedentaria		
Order Chaetopterida		
Family Chaetopteridae (parchment worms)		
119. *Spiochaetopterus costarum* Gitay, 1969	Kristian Fauchald - USNM	BR-149, -152, -218 [MBD]
Order Sabellida		
Family Serpulidae (feather-duster worms)	Mary E. Rice - USNM	
120. *Ditrupa* sp.	Pettibone, 1982, p. 38	BR-158, -214 [MBD]
PHYLUM POGONOPHORA (beard worms)		
Order Thecanephria		
Family Sclerolinidae		
121. *Sclerolinum* sp.	Webb, 1964, p. 47-58	BR-160, -161 [MBD]
PHYLUM ARTHROPODA		
Subphylum Crustacea (crustaceans)		
Class Malacostraca (malacostracans)		
Order Isopoda (isopods)		
Suborder Asellota		
Family Aegidae		
122. *Aega gracilipes* Hanson, 1895	Thomas E. Bowman - USNM	USNM Cat. No. 251765
Order Amphipoda (scuds)		
Suborder Gammaridea		
Family Lysianassidae		
123. *Onesimoides* sp.	J. L. Barnard - USNM	Photograph [CA]
124. *Paralicella* sp.	J. L. Barnard - USNM	BR-207 [MBD]
Order Decapoda (shrimps, lobsters & crabs)		
Suborder Pleocyemata		
Infraorder Caridea (shrimps)	Dustin D. Chivers - Calif Acad Sci	Photograph [CA]
Superfamily Atyoidea		
Family Nematocarcinidae		
125. *Nematocarcinus ensiferus* Smith	Agassiz, 1888, vol. 2, p. 46	Photograph [CA]

APPENDIX A (CONTINUED)

Organism		Identifier/Reference	Specimen No. [Location]
	Infraorder Anomura		
	Superfamily Galatheoidea		
	Family Galatheidae (squat lobsters)		
126.	*Munida microphthalma* Milne-Edwards, 1880	Austin B. Williams - NMFS	USNM Cat. No. 250719 [USNM]; BR-129 [MBD]
127.	*Munidopsis bermudezi* Chace, 1939	Austin B. Williams - NMFS	USNM Cat. No. 243936 [USNM]; BR-216 [MBD]
128.	*Munidopsis crassa* Smith, 1885	Austin B. Williams - NMFS	USNM Cat. No. 243938 [USNM]; BR-132 [MBD]
129.	*Munidopsis livida* (Milne-Edwards, 1886) ?	Austin B. Williams - NMFS	Photograph [CA]
130.	*Munidopsis nitida* (Milne-Edwards, 1880) ?	Austin B. Williams - NMFS	Photograph [CA]
131.	*Munidopsis rostrata* (Milne-Edwards, 1880)	Austin B. Williams - NMFS	USNM Cat. No. 243939
132.	*Munidopsis similis* Smith, 1885	Austin B. Williams - NMFS	USNM Cat. No. 243937
	Superfamily Paguroidea		
	Family Parapaguridae (hermit crabs)		
133.	*Parapagurus* sp.	Austin B. Williams - NMFS	BR-151 [MBD]
	Infraorder Brachyura (true crabs)		
	Superfamily Portunoidea		
	Family Geryonidae		
134.	*Chaceon quinquidens* Smith 1879	Daniel M. Cohen - NHM LA Co	Photograph [CA]
135.	*Chaceon* (new species)	Raymond B. Manning - USNM	Photograph [CA]
	Class Cirripedia (barnacles)		
	Order Thoracica		
	Suborder Lepadomorpha (pedunculate barnacles)		
	Family Lepadidae		
136.	*Megelasma subcarinata* Pilsbry	Thomas E. Bowman - USNM	USNM Cat. No. 250079; BR-127 [MBD]
	Family Scalpellidae		
137.	*Arcoscalpellum regium*	C. E. Herdendorf - Ohio State Univ	BR-183, -230 [MBD]
	Suborder Verrucomorpha (sessile barnacles)		
	Family Verrucidae		
138.	*Verruca* sp.	Thomas E. Bowman - USNM	USNM Acc. No. 386969
PHYLUM BRYOZOA (=ECTOPROCTA)			
	Class Gymnolaemata		
	Order Cheilostomata		
	Suborder Anasca		
	Division Malacostega		
	Family Membraniporidae		
139.	*Membranipora* sp.	Barnes 1987, p. 746	BR-159 [MBD]
	Family Calloporidae (=Alderinidae)		
140.	*Crassimarginatella* (new species ?)	Judith E. Winston - Virginia MNH	BR-302 [VMNH]
PHYLUM BRACHIOPODA (lamp shells)			
	Class Inarticulata		
	Order Acrotretida		
	Family Discinidae		
141.	*Pelagodiscus* sp. or *Discina* sp.	Marshall, 1979, p. 169; Agassiz, 1888, vol. 2, p. 77	BR-321 [MBD]
PHYLUM ECHINODERMATA (spiny-skinned animals)			
	Subphylum Crinozoa		
	Class Crinoidea (sea lilies & feather stars)		
	Subclass Articulata		
	Order Bouergueticrinida		
	Family Porphyrocrinidae (stalked crinoid)		
142.	*Porphyrocrinus* sp.	Charles G. Messing - Nova Univ	BR-322 [NU]

APPENDIX A (CONTINUED)

Organism	Identifier/Reference	Specimen No. [Location]
Order Comatulida (feather stars)		
Family Antedonidae (stalkless crinoids)		
143. *Caryometra alope* Clark, 1940	Charles G. Messing - Nova Univ	BR-323 [NU]
Subphylum Asterozoa		
Class Stelleroidea (sea stars)		
Subclass Asteroidea (starfishes)		
Order Paxillosida		
Family Astropectinidae (burrowing sea stars)		
144. *Plutonaster efflorescens* (Perrier, 1884)	Cynthia G. Ahearn - USNM	USNM Cat. No. E42513
Order Spinulosida		
Family Echinasteridae		
145. *Henricia antillarum* (Perrier, 1881)	David L. Pawson - USNM	Photograph [CA]
Order Forcipulata		
Family Pedicellasteridae		
146. *Ampheraster alaminos* Downey, 1971	Cynthia G. Ahearn - USNM	USNM Cat. No. E42514, E42520 & E43319
Family Brisingidae		
147. *Brisinga cricophora* Sladen, 1889	John E. Miller - Harbor Branch	USNM Cat. No. E42512 ; BR-136, -236 [MBD]; BR-325 [WC]
148. *Brisinga costata* Verrill, 1884	Downey 1986, p. 5-7	Photograph [CA]
Subclass Ophiuroidea (basket stars & brittle stars)		
Order Ophiurida (brittle stars)		
Family Ophiuridae		
149. *Ophiomusium lymani* Thomson, 1873	Ruth D. Turner - Harvard Univ Cynthia G. Ahearn - USNM	USNM Cat. No. E42519; BR-228 [MBD]
Family Ophiodermatidae		
150. *Bathypectinura heros* (Lyman, 1879)	Barbara Hecker - Columbia Univ Cynthia G. Ahearn - USNM	Photograph [CA] USNM Cat. No. E42517 & E42518
Subphylum Echinozoa		
Class Echinoidea (sea urchins)		
Order Echinoida		
Family Echinidae		
151. *Echinus* sp.	Gage & Tyler, 1991, p. 66	Photograph [CA]
Order Echinothuroida		
Family Echinothuridae		
152. *Araeosoma* sp.	Cynthia G. Ahearn - USNM	BR-117 [MBD]; Photograph [CA]
153. *Phormosoma* sp.	Gage & Tyler, 1991, p. 66	Photograph [CA]
Order Spatangoida (heart urchins)		
Family Asterostomatidae		
154. *Palaeobrissus hilgardi* Agassiz, 1883	David L. Pawson - USNM	USNM Cat. No. E42515
Class Holothuroidea (sea cucumbers)		
Order Aspidochirotida		
Family Synallactidae		
155. *Pseudostichopus mollis* Theel, 1886	Cynthia G. Ahearn - USNM	USNM Cat. No. E42516
Order Apodida		
Family Chiridotidae		
156. *Chiridota* (new species)	David L. Pawson - USNM	USNM Cat. No. G4125 - G4129
Order Elasipodida		
Family Deimatidae		
157. *Deima* sp.	Cynthia G. Ahearn - USNM	Photograph [CA]

APPENDIX A (CONTINUED)

Organism	Identifier/Reference	Specimen No. [Location]
PHYLUM HEMICHORDATA		
Class Enteropneusta (acorn worms)		
Family Ptychoderidae		
158. *Balanoglossus* sp.	Benito, 1982, p. 820	Photograph [CA]
PHYLUM CHORDATA		
Subphylum Urochordata (tunicates)		
Class Ascidiacea (sea squirts)		
Order Stolidobranchia (folded baskets)		
Family Styelidae		
159. *Culeolus* sp. or *Doltenia* sp.	Menzies et al., 1973, p. 158	Photograph [CA]
Subphylum Vertebrata (vertebrates)		
Class Chondrichthyes (sharks & relatives)		
Subclass Elasmobranchii		
Superorder Batoidea (rays & skates)		
Order Rajiformes		
Family Rajidae (skates)		
160. *Raja jenseni* Bigelow & Schroeder, 1950	C. Lavett Smith - Am Mus Nat Hist	Photograph [CA]
Superorder Squalomorphii		
Order Squaliformes		
Family Squalidae (dogfish sharks)		
161. *Somniosus microcephalus* (Schneider, 1801) (Greenland shark)		
	Eugenie Clark - Univ Maryland	Photograph [CA]
	Daniel M. Cohen - NHM LA Co	Photograph [CA]
	Richard H. Rosenblatt - Scripps	Photograph [CA]
Subclass Holocephalii		
Order Chimaeriformes		
Family Chimaeridae (chimaeras)	Eugenie Clark - Univ Maryland	Photograph [CA]
162. *Hydrolagus affinis* (Capello, 1868) (ghost shark)	Barbara Hecker - Columbia Univ	Photograph [CA]
	Daniel M. Cohen - NHM LA Co	Photograph [CA]
	Richard H. Rosenblatt - Scripps	Photograph [CA]
Class Osteichthyes (bony fishes)		
Subclass Actinopterygii: Superorder Teleostei		
Order Anguilliformes (eels)		
Family Synaphobranchidae		
Subfamily Synaphobranchinae (cutthroat eels)		
163. *Synaphobranchus kaupi* Johnson, 1862	Barbara Hecker - Columbia Univ	Photograph [CA]
164. *Synaphobranchus* sp.	Daniel M. Cohen - NHM LA Co	Photograph [CA]
	Richard H. Rosenblatt - Scripps	Photograph [CA]
Subfamily Simenchelyinae (pugnose eels)		
165. *Simenchelys parasiticus* Gill, 1879 (blunt-nosed eel)	Eugenie Clark- Univ Maryland	Photograph [CA]
	Daniel M. Cohen - NHM LA Co	Photograph [CA]
	Richard H. Rosenblatt - Scripps	Photograph [CA]
Family Derichthyidae (longneck eels)		
166. *Derichthys serpentinus* Gill, 1887 (serpent eel)	Wheeler, 1975, p. 176	Photograph [CA]
167. unknown species	Daniel M. Cohen - NHM LA Co	Photograph [CA]
	Richard H. Rosenblatt - Scripps	Photograph [CA]
Order Notacanthiformes		
Family Halosauridae (halosaurs)		
168. *Halosauropsis macrochir* (Günther, 1878)	Samuel B. McDowell - Rutgers Univ	Photograph [CA]
	Daniel M. Cohen - NHM LA Co	Photograph [CA]
	Richard H. Rosenblatt - Scripps	Photograph [CA]
Order Gadiformes (cods)		
Family Macrouridae (grenadiers or rattails)		
Subfamily Macrourinae		
169. *Coryphaenoides guentheri* (Vaillant, 1888)	Tomio Iwamoto - Calif Acad Sci	Photograph [CA]
170. *Coryphaenoides leptolepis* (Günther, 1877)	Barbara Hecker - Columbia Univ	Photograph [CA]

Appendix A (Continued)

Organism		Identifier/Reference	Specimen No. [Location]
171.	*Coryphaenoides armatus* (Hector, 1875)	Barbara Hecker - Columbia Univ	Photograph [CA]
		Daniel M. Cohen - NHM LA Co	Photograph [CA]
		Richard H. Rosenblatt - Scripps	Photograph [CA]
	Family Moridae (deep-sea cods)		
172.	*Antimora rostrata* Günther, 1878	Tomio Iwamoto - Calif Acad Sci	Photograph [CA]
173.	*Laemonema* sp. or *Lepidion* sp.	Daniel M. Cohen - NHM LA Co	Photograph [CA]
		Richard H. Rosenblatt - Scripps	Photograph [CA]
	Family Phycidae (phycis hakes)		
174.	*Urophycis chesteri* (Goode & Bean, 1878)	Wm. N. Eschmeyer - Calif Acad Sci	Photograph [CA]
		Barbara Hecker - Columbia Univ	Photograph [CA]
	Order Ophidiiformes		
	Family Ophidiidae (cusk eels & brotulids)		
	Subfamily Neobythitinae		
175.	*Barathrodemus manatinus* Goode & Bean, 1883	Daniel M. Cohen - NHM LA Co	Photograph [CA]
		Richard H. Rosenblatt - Scripps	Photograph [CA]
176.	*Neobythites* sp.	Goode & Bean, 1895, p. 325	Photograph [CA]
	Order Perciformes		
	Suborder Zoarcoidei		
	Family Zoarcidae (eelpouts)		
177.	*Lycodes zoarchus* Goode & Bean, 1895	C. Lavett Smith - Am Mus Nat Hist	BR-324 [AMNH]
178.	*Lycodes atlanticus* Jensen, 1904	Daniel M. Cohen - NHM LA Co	Photograph [CA]
		Richard H. Rosenblatt - Scripps	Photograph [CA]
	Order Scorpaeniformes (mail cheeked fishes)		
	Suborder Cottoidei (sculpins)		
	Family Psychrolutidae (fathead sculpins)		
179.	*Cottunculus thompsoni* Günther, 1882	Daniel M. Cohen - NHM LA Co	Photograph [CA]
		Richard H. Rosenblatt - Scripps	Photograph [CA]

Key To Specimen Number:
- BR - Blake Ridge Expedition (Museum of Biological Diversity, The Ohio State University, Columbus, OH)
- HMR - Henry M. Reiswig (Redpath Museum, McGill University, Montreal, Quebec)
- USNM - United States National Museum (Natural History, Smithsonian Institution, Washington, DC)

Specimen/Photograph Location:
- [AMNH] - American Museum of Natural History, New York, NY
- [CA] - Columbus–America Discovery Group, Columbus, OH
- [FMNH] - Florida Museum of Natural History, Gainsville, FL
- [HMR] - Redpath Museum, McGill University, Montreal, Quebec
- [MBD] - Museum of Biological Diversity, The Ohio State University, Columbus, OH
- [MCZ] - Museum of Comparative Zoology, Harvard University, Cambridge, MA
- [NU] - Oceanographic Center, Nova University, Dania, FL
- [ORNL] - Oak Ridge National Laboratory, Oak Ridge, TN
- [USGS] - U.S. Geological Survey, Reston, VA
- [USNM] - National Museum of Natural History, Smithsonian Institution, Washington, DC
- [VMNH] - Virginia Museum of Natural History, Martinsville, VA
- [WC] - Department of Biology, Wesleyan College, Macon, GA

Note: The classification of plants and invertebrate animals used in this appendix generally follows the taxonomic system published in Parker (1982) and the classification used for fishes follows Eschmeyer (1990). Nomenclature follows the recommendations of the International Code of Zoological Nomenclature (3rd edition, 1985) in that when the describer's (author's) name is contained within parentheses the genus name has been changed. Organisms identified from photographs should be considered as a tentative listing.

APPENDIX B

Taxonomic listing of the benthic and planktonic foraminifera typical of the North Atlantic Ocean in the vicinity of SS Central America *shipwreck site.*

Taxa	Depth Distribution
BENTHIC	
Order Foraminifera	
Suborder Textulariina	
Superfamily Ammodiscoidea	
Family Astrorhizidae	
Hyperammina elongata Brady	ubiquitous
Rhabdammina abyssorum Carpenter	>200 m
Saccorhiza ramosa (Brady)	>200 m
Family Saccamminidae	
Hemisphaerammina bradyi Loeblich & Tappan	ubiquitous
Psammosphaera fusca Schultze	ubiquitous
Pelosina variabilis Brady	>200 m
Saccammina atlantica (Cushman)	ubiquitous
Saccammina sphaerica Brady	>200 m
Family Ammodiscidae	
Ammodiscus incertus d'Orbigny	>200 m
Tolypammina vagans (Brady)	>200 m
Superfamily Lituoloidea	
Family Hormosinidae	
Reophax dentaliniformis Brady	ubiquitous
Family Lituolidae	
Ammobaculites agglutinans (d'Orbigny)	>200 m
Cribrostomoides subglobosum (Sars)	>200 m
Family Loftusiidae	
Cyclammina cancellata Brady	>200 m
Family Textulariidae	
Textularia secasensis Lalicker & McCulloch	<200 m
Family Trochamminidae	
Trochammina squamata Jones & Parker	<200 m
Family Valvulinidae	
Eggerella bradyi Cushman	>200 m
Karreriella bradyi (Cushman)	>200 m
Suborder Miliolina	
Superfamily Milioloidea	
Family Miliolidae	
Pyrgo subsphaerica (d'Orbigny)	ubiquitous
Quinqueloculina seminula (Linnaeus)	<200 m
Spiroloculina depressa d'Orbigny	<200 m
Family Soritidae	
Peneroplis proteus d'Orbigny	<200 m
Suborder Lagenina	
Superfamily Nodosarioidea	
Family Vaginulinidae	
Astacolus albatrossi (Cushman)	>200 m
Astacolus occidentalis (Cushman)	ubiquitous
Dentalina flintii (Cushman)	>200 m
Dentalina frobisherensis Loeblich & Tappan	ubiquitous
Dentalina subsoluta (Cushman)	>200 m
Marginulina bacheii Bailey	ubiquitous
Marginulina glabra d'Orbigny	>200 m
Marginulina spinigera (Brady)	>200 m
Suborder Rotaliina	
Superfamily Robertinoidea	

APPENDIX B (Continued)

Taxa	Depth Distribution
Family Epistominidae	
Hoeglundina elegans (d'Orbigny)	ubiquitous
Superfamily Buliminoidea	
Family Bolivinitidae	
Bolivina paula Cushman & Cahill	<200 m
Bolivina pseudoplicata Heron-Allen & Earland	<200 m
Bolivina subaenariensis Cushman	ubiquitous
Family Buliminidae	
Bulimina aculeata d'Orbigny	ubiquitous
Bulimina exilis Brady	ubiquitous
Bulimina inflata Seguenza	>200 m
Bulimina marginata d'Orbigny	ubiquitous
Reussella atlantica (Cushman)	<200 m
Family Uvigerinidae	
Trifarina angulosa (Williamson)	ubiquitous
Uvigerina peregrina Cushman	>200 m
Uvigerina hispidocostata Cushman & Todd	ubiquitous
Superfamily Discorboidea	
Family Eponididae	
Eponides umbonatus (Reuss)	ubiquitous
Family Planorbulinidae	
Planorbulina mediterranensis d'Orbigny	<200 m
Superfamily Cassidulinoidea	
Family Cassidulinidae	
Cassidulina subglobosa Brady	ubiquitous
PLANKTONIC	
Superfamily Globigerinoidea (planktonic foraminifera)	
Family Catapsydracidae	
Globoquadrina dutertrei (d'Orbigny)	planktonic
Pulleniatina obliquiloculata (Parker and Jones)	planktonic
Family Hastigerinidae	
Hastigerina pelagica (d'Orbigny)	planktonic
Family Globorotaliidae	
Candeina nitida (d'Orbigny)	planktonic
Globigerinita glutinata (Egger)	planktonic
Globorotalia crassaformis (d'Orbigny)	planktonic
Globorotalia hirsuta (d'Orbigny)	planktonic
Globorotalia inflata (d'Orbigny)	planktonic
Globorotalia menardii (d'Orbigny)	planktonic
Globorotalia scitula (Brady)	planktonic
Globorotalia truncatulinoides (d'Orbigny)	planktonic
Globorotalia tumida (Brady)	planktonic
Family Globigerinidae	
Globigerina bulloides d'Orbigny	planktonic
Globigerina falconensis Blow	planktonic
Globigerina humilis (Brady)	planktonic
Globigerina pachyderma (Ehrenberg)	planktonic
Globigerina quinqueloba Natland	planktonic
Globigerina rubescens d'Orbigny	planktonic
Globigerinella aequilateralis (Brady)	planktonic
Globigerinoides conglobatus (Brady)	planktonic
Globigerinoides ruber (d'Orbigny)	planktonic
Globigerinoides sacculifer (Brady)	planktonic
Orbulina universa d'Orbigny	planktonic

Data Sources: Bé et al. (1971), Culver and Buzas (1980), Cushman (1922), and Loeblich and Tappan (1964)

APPENDIX C

Hierarchical listing of artifacts recovered from the SS Central America *shipwreck.*

Ref No.	Object	Description	Site Location	Artifact No.
CATEGORY 1: STRUCTURES – artifacts created to define space for human activities				
Class: Building Component – artifacts created as separate, distinct, and generally interchangeable structural or decorative parts of structures				
1.	BRICK	Brick; reddish brown [BR-165]	Seabed	29333
2.	DOOR	Wood fragment of a door with metal latch mechanism (deadbolt) and door knob	Seabed	33688
3.	LATCH	Metal latch mechanism	Seabed	33876
4.	LATCH	Metal latch mechanism	Seabed	34102
CATEGORY 2: FURNISHINGS – artifacts created to facilitate human activity and to provide for physical needs of people				
Class: Household Accessory – artifacts created to be placed in or around a building for the convenience of people to enhance, complement, or facilitate the maintenance of their environment				
5.	STOPPER, BOTTLE	Cork bottle stopper (?)	Seabed	33955
6.	STOPPER, BOTTLE	Glass stopper with metal/glass fragment (bottle neck ?)	Seabed	33914
Class: Lighting Device – artifacts created to provide illumination				
7.	LAMP, OIL	Copper lamp; contains whale oil	Seabed	29027
8.	LAMP, OIL	Copper lamp; degraded	Seabed	30228
CATEGORY 3: PERSONAL ARTIFACTS – artifacts created to serve the personal needs of individuals as clothing, adornment, body protection, or an aid for grooming				
Class: Adornment – artifacts created to be worn on the human body or on clothing for ornamentation				
9.	BRACELET	Gold (?) bracelet with clasp; elliptical; hollow	Seabed	29043
10.	BRACELET	Metal bracelet (?); gold colored with some blue; elliptical	Seabed	29295
11.	BROOCH	Gold plated (?) brooch; center missing	Easton trunk	29207
12.	CHAIN	Chain fragments	Seabed	29286
13.	CHAIN	Chain fragments	Seabed	29314
14.	CHAIN	Chain fragments	Seabed	29316
15.	CHAIN	Jewelry fragments; possibly a chain	Seabed	29317
16.	FOB	Watch fob; dog's head; ruby (?) eyes	Easton trunk (L-5)	29197
17.	FOB	Watch fob, gold and quartz; inscription: "GJC (?) Banks"; found in box (see No. 29119)	Easton trunk (L-4)	29200
18.	FOB	Fabric from dog's head watch fob	Easton trunk (L-5)	29247
19.	JEWELRY FRAGMENT	Collection of metal rectangles	Seabed	29290
20.	JEWELRY FRAGMENT	Jewelry fragments; scalloped metal pieces (five); attached to gold wire	Seabed	29315
21.	JEWELRY FRAGMENT	Jewelry fragments	Seabed	29318
22.	NECKLACE	Chain and pendant fragment	Seabed	29313
23.	PENDANT	Metal pendant (?); flower-shaped	Seabed	29288
24.	PENDANT	Metal loop; part of a pendant (?)	Seabed	29289
25.	PIN	Gold "nugget" pin; triangular; clasp on back	Seabed	29042
26.	RING	REGARD ring; letters of name signify gems: ruby (missing), emerald, garnet amethyst, rose quartz, and diamond	Seabed	29041
Class: Clothing – artifacts created as coverings for the human body				
Subclass: Footwear – clothing and other protective items that are worn on the feet for protection or cover				
27.	BOOT	Boot or shoe fragment	Seabed	33852
28.	BOOT	Boot or shoe heel	Seabed	33976
29.	BOOT	Boot or shoe heel	Seabed	33986
30.	BOOT	Boot or shoe sole	Dement trunk	33971
31.	BOOT	Boot or shoe sole	Seabed	33974
32.	BOOT	Boot under wood fragment	Seabed	29253
33.	BOOT	Leather boot or shoe heel	Disintegrated trunk	29327
34.	BOOT	Pair of boots; wrapped in newspaper (see No. 33804)	Dement trunk	33803
35.	SHOE	Leather shoe fragment (?)	Seabed	33932
36.	SHOE	Pair of shoes	Seabed	33690
37.	SHOE	Shoe fragment	Seabed	33933
38.	SHOE	Shoe fragment (?)	Seabed	33916
39.	SHOE	Shoe fragment with thick heel	Disintegrated trunk	29325
40.	SHOE	Shoe fragment with thick heel	Disintegrated trunk	29326
41.	SHOE	Shoe sole fragment	Seabed	33975
42.	SHOE	Shoe heels	Seabed	33928
43.	SOCK	Pair of men's socks	Easton trunk (L-3)	29094
44.	SOCK	Pair of men's socks	Easton trunk (L-5)	29132

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
45.	SOCK	Pair of men's socks	Easton trunk (L-6)	29153
46.	SOCK	Pair of men's socks	Easton trunk	29169
47.	SOCK	Pair of men's socks	Easton trunk (L-6)	29171
48.	SOCK	Pair of men's socks	Easton trunk (L-6)	29182
49.	SOCK	Pair of men's socks; initials "A.I.E."	Easton trunk (L-6)	29212
50.	SOCK	Pair of men's socks	Easton trunk	29213
51.	SOCK	Pair of men's socks	Easton trunk	29214
52.	SOCK	Pair of men's socks	Easton trunk	29215
53.	SOCK	Pair of men's socks	Easton trunk	29216
54.	SOCK	Pair of men's socks	Easton trunk	29217
55.	SOCK	Pair of men's socks	Easton trunk	29218
56.	SOCK	Pair of socks	Dement trunk	33750
57.	SOCK	Pair of socks	Dement trunk	33779
58.	SOCK	Pair of socks	Dement trunk	33781
59.	SOCK	Pair of socks	Dement trunk	33784
60.	SOCK	Pair of socks	Dement trunk	33805
61.	SOCK	Pair of socks	Dement trunk	33809
62.	SOCK	Pair of socks	Dement trunk	33810
63.	SOCK	Pair of socks	Dement trunk	33811
64.	SOCK	Pair of socks	Dement trunk	33812
65.	SOCK	Pair of socks	Dement trunk	33813
66.	SOCK	Pair of socks	Dement trunk	33814
67.	SOCK	Pair of socks	Dement trunk	33815
68.	SOCK	Pair of socks	Dement trunk	33817
69.	SOCK	Sock fragment; foot missing	Seabed	33994
70.	SPAT	Fabric spat; strap; right foot (?)	Dement trunk	33783
71.	SPAT	Felt spat, twill weave lining; leather edge	Dement trunk	33818
72.	STOCKING	Women's stockings/hose	Easton trunk (L-2)	29079
73.	STOCKING	Women's stockings; mark: "BRITISH/SEA ISLAND YARN"	Easton trunk (L-1)	29051
74.	STOCKING	Women's stockings	Easton trunk (L-2)	29068
	Subclass: Outerwear – clothing that is worn on the body over undergarments or as an exterior layer of dress			
75.	BATHROBE	Men's robe	Easton trunk (L-6)	29150
76.	COAT	Men's paletot-sac style coat, wool/silk; brown (Crawford 1994)	Easton trunk (L-6)	29168
77.	COAT	Sack coat, cotton; plain weave (Hannel 1994)	Dement trunk	33780
78.	COAT	Sack coat, linen; plain weave; hip length (Hannel 1994)	Dement trunk	33782
79.	COAT	Sack coat, linen; plain weave (Hannel 1994)	Dement trunk	33785
80.	COAT, FROCK	Men's double breasted frock coat, wool; brown (Crawford 1994); silk lining (Jakes and Wang 1993)	Easton trunk (L-6)	29148
81.	COAT, FROCK	Frock coat, wool; twill weave; dark brown (Hannel 1994)	Dement trunk	33775
82.	DRESS	Women's dress; cartridge pleating	Easton trunk (L-1)	29080
83.	GOWN, DRESSING	Women's dressing gown or robe, cotton; rose-colored print	Easton trunk (L-1)	29057
84.	GOWN, DRESSING	Women's dressing gown or robe; lace collar	Easton trunk (L-2)	29078
85.	GOWN, DRESSING	Women's fancy robe; long sash in belt loops	Easton trunk (L-2)	29060
86.	NIGHTGOWN	Men's nightshirt	Easton trunk (L-6)	29152
87.	NIGHTGOWN	Men's nightshirt	Easton trunk (L-6)	29159
88.	PANTS	Men's classic formal trousers, wool; brown, red and gold fibers make up pattern throughout; button fly (Crawford 1994)	Easton trunk (L-1)	29049
89.	PANTS	Men's classic formal trousers, wool (Jakes and Wang 1993); blue; five-button fly (Crawford 1994)	Easton trunk (L-6)	29164
90.	PANTS	Pants, linen; white; alternating twill weave creates a striped effect similar to herringbone; five-button fly (Hannel 1994)	Dement trunk	33801
91.	PANTS	Pants, linen; white; twill weave; five-button fly (Hannel 1994)	Dement trunk	33807
92.	PANTS	Pants, linen; white or gray; plain weave (Hannel 1994)	Dement trunk	33816
93.	PANTS	Trouser garment (?)	Dement trunk	33751
94.	PANTS	Trouser garment (?)	Dement trunk	33788
95.	PANTS	Women's trousers (Crawford 1994)	Easton trunk (L-1)	29052
96.	SHIRT, DRESS	Men's shirt with collar, cotton; white with purple printed design; plain weave (Crawford 1994)	Easton trunk (L-1)	29064
97.	SHIRT, DRESS	Men's shirt with collar, linen and cotton; white with twining design along front and embroidery; plain weave; inscription: "A. Ives Easton 1" (Crawford 1994)	Easton trunk (L-2)	29065
98.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-2)	29066
99.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave; inscription: "A. Ives Easton 4" (Crawford 1994)	Easton trunk (L-2)	29067
100.	SHIRT, DRESS	Men's shirt, linen; white; plain weave; inscription: "A. Ives Easton No. 17" (Crawford 1994)	Easton trunk (L-1)	29069

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
101.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Jakes and Wang 1993, Crawford 1994)	Easton trunk (L-2)	29074
102.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-3)	29084
103.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave; mark: "W. Ralston" (Crawford 1994)	Easton trunk (L-4)	29114
104.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-6)	29154
105.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-6)	29155
106.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-6)	29156
107.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-6)	29157
108.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave (Crawford 1994)	Easton trunk (L-6)	29158
109.	SHIRT, DRESS	Men's shirt with collar, linen; white; plain weave; inscription: "A. Ives Easton 3" (Crawford 1994)	Easton trunk (L-1)	29077
110.	SHIRT, DRESS	Men's evening dress shirt; larger size	Dement trunk	33716
111.	SHIRT, DRESS	Men's shirt; larger size	Dement trunk	33720
112.	SHIRT, DRESS	Men's shirt with collar; larger size	Dement trunk	33721
113.	SHIRT, DRESS	Men's shirt, cotton; star pattern; smaller size	Dement trunk	33724
114.	SHIRT, DRESS	Men's shirt; patterned; smaller size	Dement trunk	33730
115.	SHIRT, DRESS	Men's shirt; larger size	Dement trunk	33745
116.	VEST	Vest, cotton; white; piqué; shawl collar; six domed metal buttons with an eagle design (eagle's wings spread with a shield bearing a "V" on its chest and three arrows in the left claw and an olive branch in the right) (Hannel 1994)	Dement trunk	33710
117.	VEST	Vest, silk; gold; shawl collar (Hannel 1994)	Dement trunk	33708
118.	VEST	Vest, wool; twill weave (Hannel 1994)	Dement trunk	33776
119.	WAISTCOAT	Men's waistcoat, cotton; white; floral motif in brown; shawl collar (Crawford 1994)	Easton trunk (L-6)	29176
120.	WAISTCOAT	Men's waistcoat, cotton; white; shawl collar; evening dress (Crawford 1994)	Easton trunk (L-6)	29180
121.	WAISTCOAT	Men's waistcoat, cotton; floral and abstract design in brown; shawl collar; double breasted (Crawford 1994)	Easton trunk (L-6)	29181
122.	WAISTCOAT	Men's waistcoat, silk; green; shawl collar (Crawford 1994); quill pen in right pocket (see No. 29298)	Easton trunk (L-6)	29170
123.	WAISTCOAT	Men's waistcoat, silk; brown; shawl collar (Crawford 1994); pen nib found in right pocket (see No. 29297)	Easton trunk (L-6)	29178
	Subclass: Underwear – clothing that is worn beneath outerwear to protect or cover the body			
124.	BLOOMERS	Women's bloomers	Easton trunk (L-2)	29048
125.	BLOOMERS	Women's split bloomers (crotchless)	Easton trunk (L-2)	29059
126.	CHEMISE	Women's chemise, eyelet and lace	Easton trunk (L-1)	29050
127.	CHEMISE	Women's chemise	Easton trunk (L-2)	29055
128.	CHEMISE	Women's chemise	Easton trunk (L-2)	29076
129.	DRAWERS	Men's drawers	Easton trunk	29062
130.	DRAWERS	Men's drawers	Easton trunk (L-4)	29120
131.	DRAWERS	Men's drawers	Easton trunk (L-5)	29140
132.	DRAWERS	Men's drawers	Easton trunk (L-6)	29162
133.	DRAWERS	Men's drawers	Easton trunk (L-6)	29166
134.	DRAWERS	Men's drawers, cotton (Jakes and Wang 1993)	Easton trunk (L-2)	29056
135.	DRAWERS	Men's long underwear	Easton trunk (L-6)	29160
136.	DRAWERS	Men's long underwear	Easton trunk (L-6)	29174
137.	DRAWERS	Men's long underwear	Easton trunk (L-6)	29167
138.	DRAWERS	Men's long underwear, wool/cotton (Jakes and Wang 1993)	Easton trunk (L-6)	29163
139.	DRAWERS	Women's drawers	Easton trunk (L-1)	29053
140.	PETTICOAT	Women's petticoat	Easton trunk (L-2)	29058
141.	PETTICOAT	Women's petticoat	Easton trunk (L-2)	29073
142.	UNDERSHIRT	Long underwear shirt	Dement trunk	33792
143.	UNDERSHIRT	Long underwear shirt	Dement trunk	33793
144.	UNDERSHIRT	Long underwear shirt	Dement trunk	33798
145.	UNDERSHIRT	Long underwear shirt	Dement trunk	33799
146.	UNDERSHIRT	Long underwear shirt	Dement trunk	33800
147.	UNDERSHIRT	Long underwear shirt	Dement trunk	33819
148.	UNDERSHIRT	Long underwear shirt, knitted wool; "Merino finish"	Dement trunk	33796
149.	UNDERSHIRT	Men's undershirt	Easton trunk (L-2)	29054
150.	UNDERSHIRT	Men's undershirt	Easton trunk (L-2)	29075
151.	UNDERSHIRT	Men's undershirt	Easton trunk (L-6)	29165
152.	UNDERSHIRT	Men's undershirt	Dement trunk	33707
153.	UNDERSHIRT	Men's undershirt	Dement trunk	33709
154.	UNDERSHIRT	Men's undershirt, wool (Jakes and Wang 1993)	Easton trunk (L-1)	29081
155.	UNDERSHIRT	Women's undershirt	Easton trunk (L-1)	29063

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
		Subclass: Accessory – artifacts created to be used in association with clothing		
156.	ASCOT	Men's ascot or scarf, silk; black ground with gold embroidery design (Jakes and Wang 1993, Crawford 1994)	Easton trunk (L-3)	29095
157.	ASCOT	Men's ascot or scarf, silk; gold ground with purple fish hooks printed on fabric (Crawford 1994)	Easton trunk (L-3)	29096
158.	ASCOT	Men's ascot or scarf, silk; brown (Crawford 1994)	Easton trunk (L-5)	29134
159.	BELT	Belt, silk; with buckle (see No. 29263)	Easton trunk	29277
160.	BELT	Belt fragment and buckle	Dement trunk	33996
161.	BUCKLE	Buckle	Seabed	29259
162.	BUCKLE	Buckle fragment	Easton trunk	29284
163.	BUCKLE, BELT	Gold buckle (see No. 29277); three pieces	Easton trunk	29263
164.	BUTTON	Wood button; brown; four-holed	Easton trunk	29294
165.	BUTTON	Button; small; flat; toroid-shaped	Easton trunk	29308
166.	BUTTON	Button fragments (two); "dorset"; from shirt (see No. 29066)	Easton trunk (L-2)	29312
167.	BUTTON	Buttons, assorted	Dement trunk	33844
168.	BUTTON	Buttons (six) and one bead	Dement trunk	33875
169.	BUTTON	Buttons; white	Dement trunk	33845
170.	BUTTON	Metal buttons (two)	Dement trunk	33898
171.	BUTTON	Metal buttons (two); gray	Dement trunk	33900
172.	BUTTON	Wood button; four-holed; large (2.4 cm)	Dement trunk	33760
173.	BUTTON	Button fragments; found with trunk lining (see No. 33705)	Dement trunk	33908
174.	BUTTON	Button; white	Seabed	34004
175.	BUTTON	Metal buttons (two); brown; ball-shaped with loop	Seabed	34018
176.	BUTTON	Shell button (?); white	Seabed	33977
177.	BUTTON	Shell button (?); white	Seabed	33978
178.	BUTTON	Shell button (?); white	Seabed	33979
179.	BUTTON	Shell button (?); white	Seabed	33981
180.	BUTTON	Wood button; brown	Seabed	33980
181.	BUTTON	Wood button; brown	Seabed	33982
182.	BUTTON	Wood button; brown	Seabed	34074
183.	CLASP	Metal clasp	Easton trunk	29299
184.	CLASP	Pair of clasps	Easton trunk	29044
185.	COLLAR	Part of a men's collar, fabric; mark: "A. I. Easton"	Easton trunk (L-4)	29115
186.	COLLAR	Men's collar with square ends, linen; white (Jakes and Wang 1993, Crawford 1994)	Easton trunk (L-3)	29085
187.	COLLAR	Men's collar with square ends; white; excellent condition (Crawford 1994)	Easton trunk (L-6)	29161
188.	COLLAR	Men's collar	Easton trunk (L-5)	29141
189.	COLLAR	Collar fragments with square ends, linen; white (Crawford 1994)	Easton trunk	29239
190.	COLLAR	Men's collar	Dement trunk	33712
191.	COLLAR	Men's collar	Dement trunk	33713
192.	COLLAR	Men's collar	Dement trunk	33714
193.	COLLAR	Men's collar	Dement trunk	33715
194.	COLLAR	Men's collar	Dement trunk	33718
195.	COLLAR	Men's collar	Dement trunk	33722
196.	COLLAR	Men's collar	Dement trunk	33723
197.	COLLAR	Men's collar	Dement trunk	33732
198.	COLLAR	Men's collar	Dement trunk	33746
199.	COLLAR	Men's collar; detachable	Dement trunk	33820
200.	CRAVAT	Men's cravat	Easton trunk (L-3)	29086
201.	CRAVAT	Men's cravat or joinville, silk; blue or brown (Crawford 1994)	Easton trunk (L-3)	29104
202.	CRAVAT	Men's cravat or joinville, silk; brown (Crawford 1994)	Easton trunk (L-3)	29108
203.	CRAVAT	Men's cravat or joinville, silk; brown (Crawford 1994)	Easton trunk (L-5)	29138
204.	CRAVAT	Men's cravat or joinville, silk and cotton; blue/brown (Crawford 1994)	Easton trunk (L-3)	29107
205.	CRAVAT	Men's cravat or joinville, silk and cotton; brown (Crawford 1994)	Easton trunk (L-3)	29105
206.	CRAVAT	Men's cravat or joinville, silk and cotton; brown (Crawford 1994)	Easton trunk (L-3)	29088
207.	GLOVE	Pair of men's gloves; found in right gun pocket of coat (see No. 29148)	Easton trunk (L-6)	29282
208.	GLOVE	Pair of women's gloves	Easton trunk (L-3)	29098
209.	GLOVE	Pair of women's gloves	Easton trunk (L-3)	29211
210.	GLOVE	Pair of gloves	Dement trunk	34077
211.	HOOK	Hook and eye set (?)	Seabed	34014
212.	HOOK	Hook and eye set (?)	Seabed	34028
213.	LINK, CUFF	Pair of cuff links	Easton trunk (L-5)	29201
214.	NECKTIE	Men's tie, cotton; black and tan print on white; found with vest (see No. 29178) (Crawford 1994)	Easton trunk (L-6)	29296
215.	NECKTIE	Men's tie, silk; blue with gold printed lettering (Jakes and Wang 1993, Crawford 1994)	Easton trunk (L-3)	29099
216.	NECKTIE	Men's tie, silk; blue (Crawford 1994)	Easton trunk (L-3)	29103

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
217.	NECKTIE	Men's tie, silk; blue (Crawford 1994)	Easton trunk (L-3)	29106
218.	NECKTIE	Men's tie, silk; brown (Crawford 1994)	Easton trunk (L-3)	29101
219.	NECKTIE	Men's tie, silk; brown (Crawford 1994)	Easton trunk (L-3)	29102
220.	NECKTIE	Men's tie, silk; gold with brown/black stripes (Crawford 1994)	Easton trunk (L-3)	29100
221.	NECKTIE	Men's tie, silk (?); black	Dement trunk	33752
222.	SASH	Men's sash; ribbed fabric	Dement trunk	33719
223.	SCARF	Men's scarf; pattern of red dots and black lines	Dement trunk	33711
224.	SCARF	Men's scarf; polka dot pattern	Dement trunk	33731
225.	SCARF	Men's scarf; plaid fabric with wide, striped border	Dement trunk	33778
226.	SCARF	Men's scarf; patterned fabric, plaid (?)	Dement trunk	33789
227.	SCARF	Men's scarf; plaid pattern	Dement trunk	33790
228.	SCARF	Men's scarf; series of diamonds and dots in a cross pattern	Dement trunk	33791
229.	STUD	Eight studs (?) attached to paper card	Dement trunk	33766
230.	STUD	Three gold studs	Easton trunk (L-5)	29202
231.	SUSPENDERS	Pair of suspenders, canvas; cream colored; found with pants (see No. 29049)	Easton trunk (L-1)	29322
	Class: Personal Gear – artifacts created to be used by individuals as a personal carrying device, a protective apparatus, a personal aid, or personal smoking equipment and supplies			
232.	BANDBOX	Box containing ties (see Nos. 29099, 29108)	Easton trunk (L-4)	29111
233.	CASE, PHOTOGRAPH	Wooden case with glass pane; photograph case (?)	Seabed	33825
234.	CASE, PHOTOGRAPH	Case with degraded photograph (?)	Seabed	33830
235.	CASE, PHOTOGRAPH	Photograph case (?); unopened	Seabed	33831
236.	CIGAR	Cigars, no labels	Dement trunk	33728
237.	CIGAR	Cigars, no labels	Dement trunk	33753
238.	CIGAR	Two rolled cigars	Dement trunk	33891
239.	CIGAR	Five cylindrical cigars, rough surface; veins of tobacco leaves visible; various lengths	Dement trunk	34047
240.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29071
241.	HANDKERCHIEF	Men's handkerchief	Easton trunk (L-5)	29127
242.	HANDKERCHIEF	Men's handkerchief	Easton trunk (L-5)	29128
243.	HANDKERCHIEF	Men's handkerchief	Easton trunk (L-5)	29129
244.	HANDKERCHIEF	Men's handkerchief	Easton trunk (L-5)	29130
245.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29219
246.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29220
247.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29221
248.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29222
249.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29223
250.	HANDKERCHIEF	Men's handkerchief	Easton trunk	29225
251.	HANDKERCHIEF	Men's handkerchief, cotton and linen	Easton trunk (L-5)	29131
252.	HANDKERCHIEF	Men's handkerchief; found in pocket of coat (see No. 29148) (Crawford 1994)	Easton trunk (L-6)	29149
253.	HANDKERCHIEF	Women's handkerchief, linen (Jakes and Wang 1993)	Easton trunk (L-1)	29224
254.	HANDKERCHIEF	Handkerchief; plain	Dement trunk	33733
255.	HANDKERCHIEF	Handkerchief; two selvage edges; two rolled edges	Dement trunk	33729
256.	HANDKERCHIEF	Handkerchief; two selvage edges; two rolled edges; border	Dement trunk	33717
257.	KNIFE, POCKET	Pocket knife case; blades missing	Seabed	33842
258.	KNIFE, POCKET	Pocket knife, metal with wood on handle	Seabed	34086
259.	PIPE	Ceramic pipe; whitish with rust stains; resin present in bowl	Seabed	33695
260.	TOBACCO	Mass or quid of tobacco (?)	Dement trunk	33754
261.	TOBACCO	Mass or quid of tobacco (?)	Dement trunk	33736
262.	TONGS	Tongs, wooden (glove implement ?)	Easton trunk (L-4)	29198
263.	TRUNK	Trunk, larger half (lower); brown leather; rectangular; leather handle at right front side; latch at front center; 23 cm deep, 43 cm wide, and 76 cm long	Easton trunk	29254
264.	TRUNK	Trunk, smaller half (upper); 21 cm deep, 43 cm wide, and 76 cm long; stamped inscription: "Made by John Cattnach, Wall Street, New York"	Easton trunk	29255
265.	TRUNK	Trunk baffle	Easton trunk	29083
266.	TRUNK	Trunk divider	Easton trunk	29082
267.	TRUNK	Trunk lining	Easton trunk (L-6)	29177
268.	TRUNK	Trunk lining	Easton trunk (L-6)	29179
269.	TRUNK	Trunk lining	Easton trunk	29183
270.	TRUNK	Trunk lining	Easton trunk	29184
271.	TRUNK	Trunk lining	Easton trunk	29187
272.	TRUNK	Trunk lining	Easton trunk	29188
273.	TRUNK	Trunk lining, linen (Jakes and Wang 1993)	Easton trunk (L-5)	29142
274.	TRUNK	Trunk lining baffle	Easton trunk	29185
275.	TRUNK	Trunk lining fragment	Easton trunk	29228
276.	TRUNK	Trunk divider or shelf	Easton trunk	29146

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
277.	TRUNK	Paper from trunk shelf	Easton trunk	29151
278.	TRUNK	Shelf paper fragment from trunk divider (see No. 29146)	Easton trunk	29147
279.	TRUNK	Trunk strap	Easton trunk (L-5)	29133
280.	TRUNK	Trunk, leather	Dement trunk	33701
281.	TRUNK	Trunk divider, wood	Dement trunk	33725
282.	TRUNK	Trunk divider	Dement trunk	33726
283.	TRUNK	Trunk divider	Dement trunk	33727
284.	TRUNK	Trunk divider	Dement trunk	33774
285.	TRUNK	Trunk handle fragment	Dement trunk	33925
286.	TRUNK	Trunk inner frame	Dement trunk	33706
287.	TRUNK	Trunk inner frame	Dement trunk	33702
288.	TRUNK	Trunk inner frame	Dement trunk	33703
289.	TRUNK	Trunk lid lining	Dement trunk	33704
290.	TRUNK	Trunk lid lining	Dement trunk	33705
291.	TRUNK	Trunk lining, sample	Dement trunk	33895
292.	TRUNK	Trunk lining, sample	Dement trunk	33896
293.	TRUNK	Trunk support bar; left side	Dement trunk	33773
294.	TRUNK	Trunk ties	Dement trunk	33740
295.	TRUNK	Leather/wood fragment with fastener (trunk ?)	Disintegrated trunk	29323
296.	TRUNK	Wood fragment with latch markings (trunk ?)	Disintegrated trunk	29324
297.	TRUNK	Leather strap fragment (trunk ?)	Seabed	33938
298.	TRUNK	Metal/fabric fragment (trunk ?)	Seabed	33924
299.	TRUNK	Metal/fabric fragment (trunk ?)	Seabed	33929
300.	TRUNK	Wood fragment (trunk ?)	Seabed	33934
Class: Toilet Article – artifacts created to be used for personal care, hygiene, or grooming				
301.	BASIN	Basin; 12 facets; broken	Seabed	29237
302.	BASIN	Basin; 12 facets; broken	Seabed	33693
303.	BASIN	Wash basin; white; 10 facets; mark on base: "IRONSTONE CHINA/J. F."; British Royal Arms (lion and unicorn flanking quartered shield)	Seabed	29001
304.	BASIN	Wash basin; pinkish gray; deep bowl; mark on base: "IRONSTONE CHINA/J. F."; British Royal Arms (lion and unicorn flanking quartered shield)	Seabed	29002
305.	BASIN	Wash basin; whitish beige; rounded; 12 facets; mark on base: "IRONSTONE/CHINA/LIVESLEY . POWELL"	Seabed	29009
306.	BASIN	Bowl with chip at base	Seabed	30227
307.	BASIN	Bowl; 12 facets	Seabed	33668
308.	BOTTLE, TOILET	Bay water bottle (see No. 29196)	Easton trunk (L-1)	29061
309.	BOTTLE, TOILET	Cologne bottle wrapped in German label (see No. 29246)	Easton trunk	29245
310.	BOTTLE, TOILET	Cologne bottle wrapped in German label (see No. 29249)	Easton trunk	29248
311.	BOTTLE, TOILET	Cologne bottle wrapped in German label (see No. 29251)	Easton trunk	29250
312.	BOTTLE, TOILET	Bottle, perfume	Seabed	29033
313.	BRUSH	Mustache brush (?), hard rubber; mark on handle: "B. B. THAYER/APOTHECARY/SAN FRANCISCO CALA"	Easton trunk (L-4)	29193
314.	COMB	Comb, fine toothed	Easton trunk (L-5)	29135
315.	COMB	Comb fragment; decorative hair comb	Seabed	29238
316.	DISH, SOAP	Soap dish, ceramic; white; 11 circular holes in bottom	Seabed	29016
317.	DISH, SOAP	Soap dish, ceramic; white; mark on bottom corner: "XI"	Seabed	29019
318.	DISH, SOAP	Soap dish base, ceramic; white	Seabed	29015
319.	DISH, SOAP	Soap dish base, ceramic; white	Seabed	29020
320.	HAIRBRUSH	Brush with wooden back	Easton trunk	29252
321.	HAIRBRUSH	Hair or scalp brush; black; rubber base	Disintegrated trunk	29328
322.	JAR, COSMETIC	Bear's grease jar lid, ceramic; white with black and gray lettering: "HIGHLY PERFUMED BEAR'S GREASE/For Beautifying & Strengthening the Hair/ PREPARED by X. BAZIN,/114 Chesnut St. PHILADELPHIA."	Seabed	29018
323.	JAR, COSMETIC	Cream jar; white; mark: "B. B. THAYER & Co./Apothecaries,/SAN FRANCISCO CA"	Seabed	33840
324.	JAR, COSMETIC	Shaving cream jar lid, ceramic; white with black and gray lettering: "ROUSSEL'S/ UNRIVALLED/PREMIUM/SHAVING CREAM/Gold & Silver Medals awarded/by the Institutes of New York/Philadelphia & Boston/EUGENE ROUSSEL/114. Chestnut St./PHILADELPHIA."	Seabed	29017
325.	KIT, TOILET	Hygiene instrument (feminine douche) in fabric-covered purse; incised mark on bulb: "DR. MATESON'S (?)/ELASTIC/INJECTING INSTRUMENT"; instruction sheet	Easton trunk (L-6)	29195
326.	KIT, TOILET	Leather shaving box with two razors, three brushes, and shaving soap	Dement trunk	33735
327.	PITCHER	Pitcher, wash water (?); ironstone; white; faceted; fluted edge; mark on base: "IRONSTONE CHINA/J. F."; British Royal Arms (lion and unicorn flanking quartered shield)	Seabed	29000

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
328.	PITCHER	Pitcher, wash water (?); grayish white; 10 facets; mark on base: "IRONSTONE CHINA/J. F."; British Royal Arms (lion and unicorn flanking quartered shield)	Seabed	29004
329.	PITCHER	Pitcher, wash water (?); grayish white; molded style; mark on base: "IRONSTONE CHINA/J. F."; British Royal Arms (lion and unicorn flanking quartered shield)	Seabed	29005
330.	PITCHER	Pitcher, wash water (?)	Seabed	33664
331.	PITCHER	Pitcher fragment; white; ironstone mark	Seabed	29012
332.	PITCHER	Pitcher fragment; white; ironstone mark	Seabed	29013
333.	POT, CHAMBER	Chamber pot; white; handle on one side; inscription: "Maddock's Patent Ironstone China"	Seabed	29007
334.	RAZOR	Shaving razor, bone (?); brown	Seabed	33841
335.	SOAP	Soap or polish (?); wrapped in paper (see No. 33762) with label (see No. 33763)	Dement trunk	33761
336.	TOOTHBRUSH	Toothbrush, hard rubber; mark on handle: "WARRANTED/W. H. SMITH (?) & Co. SECURE"	Easton trunk (L-4)	29194
337.	TOOTHBRUSH	Toothbrushes (two); mark: "IMPROVED PATENTED" separated by the imprint of a crown	Seabed	34091
338.	TOWEL, HAND	Hand towel, linen	Easton trunk (L-1)	29070

CATEGORY 4: TOOLS AND EQUIPMENT FOR MATERIALS – tools, equipment, and supplies created to manage, oversee, capture, harvest, or collect resources and to transform or modify particular materials, both raw and processed

Class: Food Tools and Equipment – tools, equipment, and supplies created for the processing, storage, and preparation of food or beverages for human consumption

Subclass: Food Service Tools and Equipment – tools, equipment, and supplies created for the service, presentation, or consumption of food or beverages by humans

Ref No.	Object	Description	Site Location	Artifact No.
339.	BOTTLE	Ale or beer bottle, glass; dark brown or black; corked with liquid inside	Seabed	8002
340.	BOTTLE	Beer bottle	Seabed	33678
341.	BOTTLE	Beer bottle	Seabed	33679
342.	BOTTLE	Beer bottle	Seabed	33681
343.	BOTTLE	Beer bottle	Seabed	33682
344.	BOTTLE	Beer bottle	Seabed	33683
345.	BOTTLE	Beer bottle	Seabed	33684
346.	BOTTLE	Beer bottle	Seabed	33685
347.	BOTTLE	Beer bottle; brown; cork intact	Seabed	33680
348.	BOTTLE	Bottle, broken	Seabed	29240
349.	BOTTLE	Bottle, stoneware; brown; molded label: "VITREOUS STONE BOTTLES, —/ WARRANTED NOT TO ABSORB/J. BOURNE & SON,/PATENTEES/DENBY & CODNOR-PARK POTTERYS (?)/NEAR DERPY"	Seabed	29021
350.	BOTTLE	Champagne bottle	Seabed	33665
351.	BOTTLE	Bottle fragment	Seabed	33858
352.	BOTTLE	Bottle fragments	Seabed	29242
353.	BOTTLE	Bottle; inscription: "—ENT"	Seabed	29025
354.	BOTTLE	Wine bottle	Seabed	33673
355.	BOTTLE	Wine bottle	Seabed	29024
356.	BOTTLE	Wine bottle	Seabed	19001
357.	BOTTLE	Wine bottle; chipped lip	Seabed	33674
358.	BOTTLE	Wine-tester bottle, blue-green glass	Seabed	8003
359.	BOTTLE	Bottle with cork; green; broken at neck	Seabed	29241
360.	BOWL	Base of broken piece of china; inscription: "IRONSTONE CHINA/J. VENABLES & Co"; British Royal Arms (lion and unicorn flanking quartered shield)	Seabed	33677
361.	DECANTER	Decanter or cruet	Seabed	33666
362.	DECANTER	Decanter or cruet	Seabed	33667
363.	DECANTER	Decanter or cruet	Seabed	29036
364.	DECANTER	Decanter or cruet	Seabed	33675
365.	DECANTER	Decanter or cruet, cut or pressed glass; clear	Seabed	29037
366.	DECANTER	Decanter or cruet, cut or pressed glass; clear	Seabed	29038
367.	DECANTER	Decanter or cruet, cut or pressed glass; clear	Seabed	29039
368.	DECANTER	Glass decanter fragment; clear	Seabed	29010
369.	DISH	Seashell-shaped dish	Seabed	33670
370.	DISH	Serving dish lid (?), ironstone; white; octagonal; knob missing	Seabed	30224
371.	DISH	Sugar dish (?); white; octagonal with a face on two opposite sides	Seabed	30223
372.	DISH	Sugar dish (?); white; octagonal with a face on two opposite sides	Seabed	33671
373.	GOBLET	Blue glass goblet	Disintegrated trunk	29022
374.	GOBLET	Small goblet; clear	Seabed	29028
375.	GOBLET	Small goblet; clear; broken	Seabed	29040
376.	MUG	Tiny mug, ceramic; ivory with blue lines at top and bottom	Seabed	29006

Appendix C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
377.	MUG	Mug, ironstone; white; 12 facets	Seabed	30225
378.	MUG	Mug, ironstone; white; round	Seabed	30226
379.	PITCHER	Small pitcher; wicker collar	Seabed	33834
380.	PITCHER, CREAM	Pitcher, cream or milk; white; leaf pattern near handle and spout; mark on base: "IMPROVED FELSPAR/C. MEIGH & SON" within floral oval	Seabed	29008
381.	PLATE, DINNER	Dinner plate; white; inscription: "Maddock's Patent Ironstone China"	Seabed	8001
382.	PLATE, DINNER	Dinner plate; white; inscription: "Maddock's Patent Ironstone China"	Seabed	29003
383.	SAUCER	Saucer; white; inscription: "Maddock's Patent Ironstone China"	Seabed	8000
384.	SAUCER	Small saucer, ironstone china (?); white	Disintegrated trunk	29011
385.	SAUCER	Tea saucer; thick	Seabed	33696
386.	SAUCER	Tea saucer; thin	Seabed	33697
387.	SPOON	Metal spoon	Seabed	33699
388.	TRAY	Silver tray; round ornamented border; 20 cm; inscription: "Ohio" (?)	Seabed	34092
Class: Metalworking Tools and Equipment – tools, equipment, and supplies created for casting, forging, machining, or fabricating metals or metal products				
389.	RIVET	Metal rivet cover	Seabed	33919
390.	RIVET	Metal rivet cover	Seabed	33936
391.	RIVET	Metal rivet cover	Seabed	33959
392.	RIVET	Metal rivet cover, copper alloy (?)	Seabed	33963
393.	RIVET	Metal rivet cover, iron	Seabed	33964
Class: Textileworking Tools and Equipment – tools, equipment, and supplies created for the preparation of materials made from fibers and the preparation of woven fabrics				
394.	PIN, STRAIGHT	Metal straight pin (silver ?)	Seabed	33973
395.	PIN, STRAIGHT	Straight pin	Seabed	34021
396.	PIN, STRAIGHT	Metal straight pin	Seabed	34022
397.	PIN, STRAIGHT	Metal straight pin, flat-headed; slightly bent	Seabed	34060
398.	PIN, STRAIGHT	Metal straight pin, flat-headed; bent at the center	Seabed	34063
399.	PIN, STRAIGHT	Metal straight pin, flat-headed	Seabed	34082
400.	PIN, STRAIGHT	Metal straight pins (silver ?)	Seabed	33972
Class: Woodworking Tools and Equipment – tools, equipment, and supplies created for the fabrication of objects from wood				
401.	BOLT	Bolts (two); embedded in a piece of leather	Seabed	33958
402.	NAIL	Metal nail, flat-headed	Seabed	29285
403.	NAIL	Metal nail; large	Seabed	33949
404.	NAIL	Metal nail; short	Seabed	33957
405.	NAIL	Metal nail, flat-headed; bent	Seabed	34015
406.	NAIL	Metal nail, flat-headed	Seabed	34017
407.	NAIL	Metal nail	Seabed	34020
408.	NAIL	Metal nail; large	Seabed	34023
409.	NAIL	Metal nail head	Seabed	34024
410.	NAIL	Metal nail fragment; flat-headed, hollow	Seabed	34025
411.	NAIL	Metal nail, round-headed	Seabed	34046
412.	NAIL	Metal nail, flat-headed	Seabed	34048
413.	NAIL	Metal nail, flat-headed	Seabed	34049
414.	NAIL	Metal nail, flat-headed	Seabed	34050
415.	NAIL	Metal nail, flat-headed	Seabed	34051
416.	NAIL	Metal nail, flat-headed; bent	Seabed	34052
417.	NAIL	Metal nail, flat-headed	Seabed	34053
418.	NAIL	Metal nail, flat-headed	Seabed	34054
419.	NAIL	Metal nail, flat-headed	Seabed	34055
420.	NAIL	Metal nail, flat-headed	Seabed	34056
421.	NAIL	Metal nail, flat-headed	Seabed	34057
422.	NAIL	Metal nail, flat-headed	Seabed	34061
423.	NAIL	Metal nail, flat-headed	Seabed	34062
424.	NAIL	Metal nail, flat-headed	Seabed	34064
425.	NAIL	Metal nail, flat-headed	Seabed	34065
426.	NAIL	Metal nail, flat-headed	Seabed	34079
427.	NAIL	Metal nails (32); various heads ranging from 2 mm to 8.5 mm	Seabed	33946
428.	NAIL	Metal nails (two) embedded in wood fragment	Seabed	33947
429.	NAIL	Metal nails (two); embedded in a fragment of rust covered wood	Seabed	33948
430.	NAIL	Nail; small; flat-headed with a small slit in the head	Seabed	29311
431.	NAIL	Nails (copper alloy ?) (two); square heads; from porthole (see No. 31034)	Seabed	34005
432.	SCREW	Screw fragment (metal ?)	Seabed	34026
433.	SPIKE	Metal spike; square head	Seabed	33851

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
CATEGORY 5: TOOLS AND EQUIPMENT FOR SCIENCE & TECHNOLOGY – tools, equipment, and supplies used for the observation of natural phenomena or to apply the knowledge gained from such observation				
Class: Armament Tools and Equipment – tools, equipment, and supplies created to be used for hunting, target-shooting, warfare, or self-protection				
Subclass: Firearm – includes all projectile-firing weapons that can be easily deployed by one person				
434.	PISTOL, DUELING	Wood grip; barrel missing	Easton trunk (L-4)	29204
435.	PISTOL, DUELING	Wood grip; barrel missing	Easton trunk (L-5)	29205
Subclass: Ammunition – includes all ammunition for armament whether intended for particular weapons, or intended to be deployed alone				
436.	BALL, SHOT	Musket balls (two) with pattern	Easton trunk (L-5)	29145
437.	BALL, SHOT	Shot ball, metal; spherical; found with scarf (see No. 33791)	Dement trunk	34075
438.	BALL, SHOT	Shot ball (?); spherical; small; found with scarf (see No. 33791)	Dement trunk	34076
439.	BALL, SHOT	Shot ball, metal; spherical; solid	Seabed	33952
440.	BALL, SHOT	Shot ball, metal; spherical	Seabed	34016
441.	BALL, SHOT	Shot ball, metal; elliptical; two ridge marks on one side	Seabed	34039
442.	BALL, SHOT	Shot ball, metal; spherical; ridge down center, half way around	Seabed	34043
443.	BALL, SHOT	Shot ball, metal; spherical	Seabed	34078
Subclass: Accessory – includes all accessories used for hunting, target-shooting, warfare, or self-protection				
444.	FLASK, POWDER	Metal powder flask with lid; incised mark: "COLTS/PATENT"; embossed eagle below mark; gunpowder in flask	Easton trunk (L-4)	29199
Class: Medical and Psychological Tools and Equipment – tools, equipment, and supplies created for the examination, testing, diagnosis, and treatment of humans				
445.	BOTTLE, MEDICINE	Glass bottle; colorless; height 13.5 cm; original contents (?)	Doctor bag	33839
446.	BOTTLE, MEDICINE	Glass bottle; colorless; front panel with raised letters: "DAVIS"; indented side panels with: "VEGETABLE" on one side and: "PAIN KILLER" on other	Doctor bag	33838
447.	BOTTLE, MEDICINE	Glass bottle; green; front panel with raised letters: "DAVIS"; indented side panels with: "VEGETABLE" on one side and: "PAIN KILLER" on other	Seabed	29030
448.	BOTTLE, MEDICINE	Glass vial; colorless; original contents (?)	Doctor bag	33837
449.	JAR, SPECIMEN	Glass jar with broken lid; cylindrical; wood covered	Doctor bag	33944
450.	SYRINGE	Glass hypodermic syringe; colorless; length 14.3 cm	Doctor bag	33836
Class: Merchandising Tools and Equipment – tools, equipment, and supplies created to facilitate or enable the exchange of goods or services				
451.	JAR	Jar, ceramic; marking on lid: "VERITABLE MOËLLE DE BOEUF./L.T. PIVER/ 155 Rue St. Martin 155/Paris/AND 160 REGENT STREET LONDON"; wrapped in fabric (see No. 29172)	Easton trunk (L-6)	29203
452.	PACK	Cotton packing material	Easton trunk	29229
453.	PACK	Cotton packing material	Dement trunk	33821
454.	PAPER, WRAPPING	Paper, wrapping (?); found around soap (see No. 33761)	Dement trunk	33762
455.	PAPER, WRAPPING	Paper, wrapping (?)	Dement trunk	33765
Class: Regulative and Protective Tools and Equipment – tools, equipment, and supplies created for controlling the behavior of people, providing security or protection of property, and carrying out nonceremonial activities of a governmental organization				
456.	HOSE, FIRE	Fire hose section; metal coupling	Seabed	29045
457.	KEY	Metal key (copper alloy) with tag: "STEWARD"	Seabed	33686
458.	PADLOCK	Metal padlock (copper alloy)	Seabed	29026
Class: Surveying and Navigational Tools and Equipment – tools, equipment, and supplies created to determine the position of an observer relative to known reference points or to indicate the form and extent of a region				
459.	GIMBAL, COMPASS	Gimbal	Seabed	33676
460.	GIMBAL, COMPASS	Gimbal peg	Seabed	33882
461.	GIMBAL, COMPASS	Gimbal piece (compass or lamp)	Seabed	33692
462.	GIMBAL, COMPASS	Screw from gimbal (see No. 33676)	Seabed	34087
463.	GIMBAL, COMPASS	Square bracket	Seabed	33883
CATEGORY 6: TOOLS AND EQUIPMENT FOR COMMUNICATION – tools, equipment, and supplies used to enable communication				
Class: Written Communication Tools and Equipment – tools, equipment, and supplies created to facilitate communication between people by means of written documents				
464.	CASE, PENCIL LEAD	Wooden case with seven graphite pieces (1.32 cm long; 1 mm thick)	Dement trunk	33767
465.	CASE, PENCIL LEAD	Wooden case with seven graphite pieces (1.32 cm long; 1 mm thick)	Dement trunk	33770
466.	ENVELOPE	Envelope; unused	Easton trunk	29276
467.	ENVELOPE	Envelope fragment; inscription: "D' J. Elmendorf" (see No. 29279)	Easton trunk (L-4)	29278

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
468.	FOIL	Loose sheets of embossing (?) silver foil with gold coin ($10 1847 U.S. gold piece, New Orleans mint); wrapped in Spanish-language newspaper (see No. 29280)	Easton trunk (L-4)	29125
469.	PAPER, WRITING	Paper sheets (two); inscription: "Dr. J. Elm—Penn Ya—"; in book of silver foil (see No. 29125); with envelope (see No. 29278)	Easton trunk (L-4)	29279
470.	PAPER, WRITING	Paper sheets (two); folded; envelope between folds (see No. 29276)	Easton trunk	29275
471.	PEN, QUILL	Metal pen nib; inscription: "The Capital Pen"	Seabed	29291
472.	PEN, QUILL	Pen nib or tip found in waistcoat pocket (see No. 29178)	Easton trunk (L-6)	29297
473.	PEN, QUILL	Quill pen found in waistcoat pocket (see No. 29170)	Easton trunk (L-6)	29298
474.	PEN, QUILL	Two quill pens (?)	Dement trunk	33741
475.	PEN, QUILL	Two quill pens (?)	Dement trunk	33742
CATEGORY 7: DISTRIBUTION AND TRANSPORTATION ARTIFACTS – artifacts created to transport or distribute animate and inanimate things				
Class: Container – artifacts created for packing, shipping, or holding goods and commodities; more specialized container forms are classified according to their function				
476.	BOTTLE	Bottle, faceted; clear	Seabed	29031
477.	BOTTLE	Bottle, slender, clear	Seabed	33700
478.	BOTTLE	Bottle, small; clear	Seabed	29029
479.	BOTTLE	Bottle, small; round; clear	Seabed	29032
480.	BOTTLE	Glass bottle; clear	Seabed	29035
481.	BOTTLE	Glass bottle, flask-shaped; clear; inscription: "CAM"	Seabed	29034
482.	BOX	Cardboard and fabric box	Seabed	29320
483.	BOX	Box, paper or cardboard	Dement trunk	33764
484.	BOX	Box, paper or cardboard; mark inside lid: "Anne"; contained packing (see No. 33821)	Dement trunk	33768
485.	BOX	Box section	Easton trunk (L-3)	29090
486.	BOX	Box section	Easton trunk (L-3)	29093
487.	BOX	Box section	Easton trunk (L-3)	29097
488.	BOX	Box section	Easton trunk	29265
489.	BOX	Box section	Easton trunk	29266
490.	BOX	Box section fragments; thin balsa-like wood and paper	Easton trunk	29267
491.	BOX	Box section fragments	Easton trunk	29272
492.	BOX	Box section; glove imprint	Easton trunk (L-3)	29091
493.	BOX	Box section; thin balsa-like wood and paper	Easton trunk (L-3)	29089
494.	BOX	Box, wrapped with fabric; five cent piece as a seal; written on fabric: "Handle with Care"	Easton trunk (L-4)	29119
495.	BOX	Gold-gilded box containing ambrotype image and note; box sealed with reddish-orange waxy substance (see Nos. 29209, 29210, 29232)	Easton trunk (L-4)	29126
496.	BOX	Metal box silver (?); length 8.5 cm, width 5 cm, and height 2 cm	Seabed	34085
497.	JAR	Jar base, ceramic; white with gray or black marble pattern	Seabed	29014
498.	JAR	Jar base, ceramic; white	Seabed	33698
499.	JAR	Glass jar fragment	Seabed	33687
Class: Water Transportation				
Subclass: Equipment – artifacts created to transport people or goods on or under water				
500.	SHIP, STEAM	Copper sheathing fastened to decayed wood [BR-327]	Seabed	19006
501.	SHIP, STEAM	Copper sheathing fastened to decayed wood [BR-328]	Seabed	19007
502.	SHIP, STEAM	Ferrous and nonferrous metal fragments and rusticles [BR-126, 134, 140, 185, 200, 252, 253, 254]	Seabed	34088
503.	SHIP, STEAM	Ship timber and wood fragments [BR-143, 164, 191, 217, 220, 221, 229, 235, 242, 249, 250, 251, 259]	Seabed	19005
504.	SHIP, STEAM	Ship timber; 56 cm long, 10 cm across, and maximum 5 cm thick	Seabed	29335
505.	SHIP, STEAM	Ship timber	Seabed	34101
Subclass: Accessory – artifacts created as accessories for the transportation of people or goods on or under water				
506.	BELL, SHIP'S	Ship's bell, bronze; 125 kg; raised inscription on band near top: "MORGAN IRON WORKS – NEW YORK – 1853"; clapper missing	Seabed	8004
507.	BELL, SHIP'S	Ship's signal (?) bell, brass; 1.3 kg	Seabed	29023
508.	CAP, MACHINE	Copper cap; bowl-shaped; rectangular with rounded corners; 27 cm long side, 23 cm short side, and 2 cm deep	Seabed	8005
509.	CHAFING GEAR	Chafing gear, leather	Seabed	29244
510.	CHAFING GEAR	Metal tube and fabric fragment	Seabed	33857
511.	DEADEYE	Wooden ring	Seabed	33859
512.	DEADEYE	Deadeye assembly, wood circular block; 18 cm diameter, 11 cm high; grooved around circumference; includes horn-shaped piece that fits within the center groove; pierced in center	Seabed	34093

Appendix C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
513.	GASKET	Gasket, rubber; oval [BR-240]	Seabed	29332
514.	PORTHOLE	Porthole, bronze (?); glass intact; hinge and screw; knob with mark: "E. —DDEN/Patent/N.Y."	Seabed	31034
CATEGORY 8: COMMUNICATION ARTIFACTS – artifacts created as expressions of human thought				
Class: Art – artifacts created for the expression and communication of ideas, values, or attitudes through images, symbols, and abstractions				
515.	CARVING	Oriental carving on exterior of box; ivory or jade (?); in cardboard box	Easton trunk (L-4)	29124
516.	FRAME, PICTURE	Metal frame; rectangular	Seabed	33970
517.	FRAME, PICTURE	Metal picture frame; rectangular	Seabed	33694
Class: Documentary Artifact – artifacts created to communicate information to people				
518.	AMBROTYPE	Ambrotype plate; gold leaf trim; found in box (see No. 29126)	Easton trunk (L-4)	29209
519.	AMBROTYPE	Ambrotype plate; image of an unidentified young man; two-piece hinged case; photographer: William Shew	Easton trunk (L-4)	29123
520.	AMBROTYPE	Ambrotype plate with cloth directly on top of glass; degraded	Seabed	33826
521.	AMBROTYPE	Ambrotype plate; glass plate surrounded by wood	Seabed	34007
522.	AMBROTYPE	Ambrotype plate; soft wood; plate seen through broken wood	Seabed	34008
523.	AMBROTYPE	Ambrotype plate; glass plate with rectangular frame with oval opening	Seabed	34009
524.	AMBROTYPE	Ambrotype plate; two photographs; metal and glass plate visible	Seabed	34010
525.	AMBROTYPE	Ambrotype plate; two wood encased photographs; plate visible	Seabed	34011
526.	AMBROTYPE	Ambrotype plate fragments	Seabed	33832
527.	AMBROTYPE	Ambrotype plate with image	Seabed	33828
528.	AMBROTYPE	Ambrotype plate with metal case	Seabed	33822
529.	AMBROTYPE	Ambrotype plate with metal case	Seabed	33823
530.	AMBROTYPE	Cluster of ambrotype fragments (two ?)	Seabed	33829
531.	AMBROTYPE	Cluster of ambrotype fragments	Seabed	33824
532.	BOOK	*Prairie Flower*	Dement trunk	33734
533.	BOOK	*Count of Monte Cristo*	Dement trunk	33739
534.	BOOK	*Lady Lee's Widowhood*	Dement trunk	33738
535.	CHECKBOOK	Checkbook and cover; checks imprinted with: "San Francisco,/WELLS, FARGO & CO., BANKERS, "	Dement trunk	33758
536.	ENVELOPE	Envelope; "Wells, Fargo & Co./OVER OUR CALIFORNIA AND COAST ROUTES."; three cent postage stamp	Dement trunk	33892
537.	ENVELOPE	Envelope, rectangular with four flaps	Dement trunk	33893
538.	ENVELOPE	Envelope, rectangular with four flaps	Dement trunk	34003
539.	ENVELOPE	Envelope fragments	Dement trunk	33943
540.	ENVELOPE	Envelope fragments (?) found with letter (see No. 29139)	Easton trunk	29269
541.	ENVELOPE	Envelope fragments (four); writing: "Mrs. R. P. Bates/Jamaica . . ."	Easton trunk	29264
542.	ENVELOPE	Paper fragments with red seal; penciled letters: "Y.UC" (?)	Easton trunk	29270
543.	LABEL	Bay water bottle label; printing: "SUPERIOR/DOUBLE DISTILLED/BAY WATER./SOLD BY/WM. H. KEITH & CO./Montgomery Street, corner of Clay, San Francisco." (see No. 29061)	Easton trunk (L-1)	29196
544.	LABEL	German label wrapping cologne bottle (see No. 29245); printing: "Kölonsches Wasser von Joseph Anton Farina altester Distillatuer in Köln"	Easton trunk	29246
545.	LABEL	German label wrapping cologne bottle (see No. 29250); printing: "Kölonsches Wasser von Joseph Anton Farina altester Distillatuer in Köln"	Easton trunk	29251
546.	LABEL	German label wrapping cologne bottle (see No. 29248); printing: "Kölonsches Wasser von Joseph Anton Farina altester Distillatuer in Köln"	Easton trunk	29249
547.	LABEL	Label, razor: "FOR RAZORS PENKN—ES & e—253 Grand Street; cor. Christie New York"	Easton trunk	29273
548.	LABEL	Paper label (?); found on soap (see No. 33761)	Dement trunk	33763
549.	LABEL	Paper label (?); found inside pair of socks (see No. 33805)	Dement trunk	33806
550.	LEDGER	Ledger book; calfskin cover (?)	Dement trunk	33757
551.	LETTER	Letter, begins: "Dear John"	Dement trunk	33769
552.	LETTER	Letter, begins: "Dear Sir"	Dement trunk	33771
553.	LETTER	Letter fragments; elegant hand writing	Easton trunk	29258
554.	LETTER	Letter fragments; found with letter (see No. 29258)	Easton trunk	29260
555.	LETTER	Letter of introduction; to B. Lancaster of Baltimore introducing Mr. John Dement of Oregon City from J. A. Simms	Dement trunk	33850
556.	LETTER	Letter; written on behalf of Mrs. Rebecca Platt Bates by the acting minister of Calvary Presbyterian Church of San Francisco to the Jamaica Presbyterian Church; in envelope (see No. 29264)	Easton trunk (L-3)	29092
557.	LETTER	Letter, two-sided; hand written; addressed to Mr. Easton from a person soliciting help (see No. 29269)	Easton trunk (L-5)	29139
558.	MEMORANDUM	Note: "Found on J. St. Sacramento/June 23rd/39"; note wrapped around a 20 franc gold coin	Easton trunk	29208

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
559.	MEMORANDUM	Paper note: "Good Morning Sir /Do You Know me"; in box with ambrotype (see Nos. 29126, 29209)	Easton trunk (L-1)	29210
560.	NEWSPAPER	Newspaper used to wrap hairbrush (see No. 29252)	Easton trunk	29072
561.	NEWSPAPER	Spanish-language newspaper fragments with red wax seal	Easton trunk	29233
562.	NEWSPAPER	Newspaper fragments from *New York News* (see No. 29206)	Easton trunk	29268
563.	NEWSPAPER	Newspaper fragments; wrapped around pair of boots (see No. 33803)	Dement trunk	33804
564.	NEWSPAPER	Newspaper fragments, bilingual (Spanish/English) wrapping book of silver foil (see No. 29125)	Easton trunk (L-4)	29280
565.	NEWSPAPER	*New York News*, Steamer Edition: "FOR CALIFORNIA, OREGON AND SANDWICH ISLANDS/MONDAY JULY 20, 1857"	Easton trunk (L-1,4)	29206
566.	NEWSPAPER	*The Sunday Varieties*, San Francisco (16 August 1857)	Dement trunk	33737
567.	SEAL	Embossed seal; pink wax on gilded box (see No. 29119); imprint of coin	Seabed	29330
568.	SEAL	Embossed seal; pink wax on gilded box (see No. 29119); imprint of coin	Seabed	29331
569.	SEAL	Wax seal fragment; red	Dement trunk	33897
570.	TAG, IDENTIFICATION	Metal door number: "2"	Seabed	33835
571.	TAG, IDENTIFICATION	Metal luggage tags; four sets of two; heart-shaped; mark: "SAN F° TO N.Y. VIA PANAMA", nos.: "206, 466, 1133, 1797" back inscription: "T.W. MOREHOUSE/ J. CITY, N.J." with leather strap	Seabed	33888
572.	TAG, IDENTIFICATION	Metal luggage tag; set of two ovals, mark: "N.Y. TO SAN F°/1078/VIA/PANAMA"; back inscription: "T.W. MOREHOUSE/J. CITY, N.J."	Seabed	33942
573.	TAG, IDENTIFICATION	Metal luggage tag; set of two ovals; mark: "N.Y. TO SAN F°/1272/VIA/PANAMA"; back inscription: "T.W. MOREHOUSE/J. CITY, N.J."; leather strap	Seabed	34012
574.	TAG, IDENTIFICATION	Metal luggage tag; heart-shaped; mark: "SAN F° TO N.Y./806/VIA/PANAMA"	Seabed	34040
575.	TAG, IDENTIFICATION	Metal luggage tag; heart-shaped; mark: "SAN F° TO N.Y./977/VIA/PANAMA"	Seabed	34041
576.	TAG, IDENTIFICATION	Metal luggage tag; mark: "—AN F°/975/VIA/PANAMA"	Seabed	34095
577.	TAG, IDENTIFICATION	Mass of metal luggage tags; mark: "SAN F° TO N.Y./VIA/PANAMA"; one among mass no. "1110"; some with leather strap attached	Seabed	33672
578.	TAG, IDENTIFICATION	Wooden tag; oval	Dement trunk	33755
579.	TINTYPE	Degraded tintype (daguerreotype ?)	Seabed	33827
Class: Exchange Medium – artifacts created to be used as a medium of exchange or as a means of obtaining specific services				
580.	COIN	Gold numismatic objects (several thousand); range from tiny quarter dollar coins to bars or ingots of hundreds of ounces each; coins of all the United States mints of the early and mid-1850's: main mint at Philadelphia and four branch mints at San Francisco, CA ("S"), New Orleans, LA ("O"), Charlotte, NC ("C"), Dahlonega, GA ("D"); privately manufactured pioneer coins and bars; foreign coins	Seabed	Multiple
581.	COIN	Silver coins; United States and foreign	Seabed	Multiple
Class: Personal Symbol – artifacts created to communicate a particular personal belief, achievement, status, or membership				
582.	MEDAL, POLITICAL	Metal badge; Order of St. Maurice and St. Lazarus; green Maltese cross (gold edged) placed saltire-wise with gold knobs on points [St. Lazarus] and enameled white, botonée-shaped cross [St. Maurice]; Italian	Seabed	33691
CATEGORY 9: RECREATIONAL ARTIFACTS – artifacts created to be used as toys or to carry on the activities of sports, games, gambling, or public entertainment				
Class: Game – artifacts created for a competitive activity based upon chance, problem-solving, or calculation rather than physical effort and conducted according to stated rules				
583.	CHECKERBOARD	Checkerboard squares (seven)	Seabed	34019
584.	CHECKERBOARD	Checkerboard squares (ten)	Seabed	33885
585.	CHECKERBOARD	Checkerboard squares (six); degraded	Seabed	33886
586.	CHECKERS	Checkers (two); black	Seabed	33846
Class: Toy – artifacts created as playthings				
587.	DOLL	Child's doll, rubber; head missing; circular mark on back: "Goodyear's patents 1848 & 49/A Rubber C°"	Seabed	33689
CATEGORY 10: UNCLASSIFIABLE ARTIFACTS – artifacts created to serve purposes that cannot be identified at the time the object is cataloged				
Class: Artifact Remnant – segments or incomplete parts of artifacts created to fulfill purposes that cannot be determined or inferred from the fragment				
588.	CERAMIC FRAGMENT	Ceramic fragment	Seabed	33950
589.	CERAMIC FRAGMENT	Ceramic fragment	Seabed	33951
590.	CERAMIC FRAGMENT	Large pottery fragment	Seabed	33860
591.	CERAMIC FRAGMENT	Pottery fragment	Seabed	33861
592.	CERAMIC FRAGMENT	Pottery fragment	Seabed	33862
593.	CERAMIC FRAGMENT	Pottery fragments	Seabed	33863
594.	CERAMIC FRAGMENT	Pottery fragments	Seabed	33864
595.	CLOTH FRAGMENT	Fabric or paper fragment	Dement trunk	33777

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
596.	CLOTH FRAGMENT	Fibers; black	Seabed	34000
597.	CLOTH FRAGMENT	Large textile fragments	Seabed	33995
598.	CLOTH FRAGMENT	Textile and paper fragments	Easton trunk	29271
599.	CLOTH FRAGMENT	Textile fragment; even weave	Easton trunk	29274
600.	CLOTH FRAGMENT	Textile fragment	Seabed	33873
601.	CLOTH FRAGMENT	Textile fragment	Seabed	33911
602.	CLOTH FRAGMENT	Textile fragment	Seabed	33918
603.	CLOTH FRAGMENT	Textile fragment	Seabed	33920
604.	CLOTH FRAGMENT	Textile fragment	Seabed	33987
605.	CLOTH FRAGMENT	Textile fragment; rectangular piece of a bag (?); mark: "MADE IN SHANGHAI"	Seabed	33988
606.	CLOTH FRAGMENT	Textile fragment	Seabed	33989
607.	CLOTH FRAGMENT	Textile fragment	Seabed	33991
608.	CLOTH FRAGMENT	Textile fragment with wood fragments	Seabed	33997
609.	CLOTH FRAGMENT	Textile fragment	Seabed	33998
610.	CLOTH FRAGMENT	Textile and leather fragments	Seabed	34001
611.	CLOTH FRAGMENT	Textile fragment	Seabed	34002
612.	CLOTH FRAGMENT	Textile fragment	Seabed	34044
613.	CLOTH FRAGMENT	Textile fragment	Seabed	34045
614.	CLOTH FRAGMENT	Textile fragments	Seabed	33878
615.	CLOTH FRAGMENT	Textile fragments	Seabed	33990
616.	CLOTH FRAGMENT	Textile fragments with wood	Seabed	33992
617.	CLOTH FRAGMENT	Textile fragments	Seabed	33993
618.	CLOTH FRAGMENT	Textile fragments	Seabed	33999
619.	GLASS FRAGMENT	Glass fragment; blue	Seabed	33915
620.	GLASS FRAGMENT	Glass fragment; blue	Seabed	33917
621.	GLASS FRAGMENT	Glass fragment	Seabed	33965
622.	GLASS FRAGMENT	Glass fragment	Seabed	33966
623.	GLASS FRAGMENT	Glass fragment	Seabed	33967
624.	GLASS FRAGMENT	Glass fragment	Seabed	33968
625.	GLASS FRAGMENT	Glass fragment	Seabed	34029
626.	GLASS FRAGMENT	Glass fragment	Seabed	34030
627.	GLASS FRAGMENT	Glass fragment	Seabed	34031
628.	GLASS FRAGMENT	Glass fragment	Seabed	34032
629.	GLASS FRAGMENT	Glass fragment	Seabed	34033
630.	GLASS FRAGMENT	Glass fragment	Seabed	34034
631.	GLASS FRAGMENT	Glass fragment	Seabed	34035
632.	GLASS FRAGMENT	Glass fragment	Seabed	34036
633.	GLASS FRAGMENT	Glass fragment	Seabed	34037
634.	GLASS FRAGMENT	Glass fragment	Seabed	34066
635.	GLASS FRAGMENT	Glass fragment	Seabed	34067
636.	GLASS FRAGMENT	Glass fragment	Seabed	34068
637.	GLASS FRAGMENT	Glass fragment	Seabed	34069
638.	GLASS FRAGMENT	Glass fragment	Seabed	34070
639.	GLASS FRAGMENT	Glass fragment	Seabed	34081
640.	GLASS FRAGMENT	Glass fragment; clear; flat; triangular [BR-150]	Seabed	34090
641.	GLASS FRAGMENT	Glass fragments	Seabed	33939
642.	GLASS FRAGMENT	Glass rectangle	Seabed	33881
643.	HANDLE	Wooden handle or knob; 12 cm long, 2 cm high, and 2 cm thick; tapered at ends; nail hole on underside	Seabed	29338
644.	HANDLE	Wooden handle; small	Seabed	33921
645.	HANDLE	Wooden handle; small	Seabed	33922
646.	HANDLE	Handle with knob	Seabed	33945
647.	LEATHER FRAGMENT	Black strip; lacquered wood (?)	Seabed	33880
648.	LEATHER FRAGMENT	Embossed leather fragment	Seabed	33877
649.	LEATHER FRAGMENT	Leather fragment	Easton trunk	29261
650.	LEATHER FRAGMENT	Leather fragment	Easton trunk	29262
651.	LEATHER FRAGMENT	Leather fragment with wood	Seabed	33879
652.	LEATHER FRAGMENT	Leather fragment	Seabed	33912
653.	LEATHER FRAGMENT	Leather fragment	Seabed	33923
654.	LEATHER FRAGMENT	Leather fragment	Seabed	33927
655.	LEATHER FRAGMENT	Leather fragment	Seabed	33931
656.	LEATHER FRAGMENT	Leather fragments (six); black; ridged	Easton trunk (L-5)	29137
657.	LEATHER FRAGMENT	Leather fragments	Seabed	33960
658.	LEATHER FRAGMENT	Leather strap	Seabed	29186
659.	LEATHER FRAGMENT	Small rectangular leather piece	Dement trunk	33802
660.	LEATHER FRAGMENT	Two strips of leather with two strips of newspaper of similar shape	Dement trunk	33743
661.	METAL FRAGMENT	Iron castings	Seabed	29243
662.	METAL FRAGMENT	Metal fragment	Easton trunk	29235

APPENDIX C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
663.	METAL FRAGMENT	Metal (?) fragment; triangular object; possibly corner support for container	Seabed	29340
664.	METAL FRAGMENT	Metal machine fragment	Seabed	33855
665.	METAL FRAGMENT	Metal fragment (?)	Dement trunk	33899
666.	METAL FRAGMENT	Metal fragment (?)	Dement trunk	33901
667.	METAL FRAGMENT	Metal or stone fragment; small	Seabed	33909
668.	METAL FRAGMENT	Metal fragments (?)	Dement trunk	33904
669.	METAL FRAGMENT	Metal fragment	Seabed	33954
670.	METAL FRAGMENT	Metal fragment	Seabed	34058
671.	METAL FRAGMENT	Metal fragment (copper alloy ?); 2 cm long	Seabed	34096
672.	METAL FRAGMENT	Metal fragment (iron ?); possibly nails	Seabed	34103
673.	METAL FRAGMENT	Metal fragments	Seabed	34038
674.	METAL FRAGMENT	Metal fragments	Seabed	34084
675.	METAL FRAGMENT	Metal fragments (numerous); rusticle features	Seabed	34097
676.	METAL FRAGMENT	Metal fragments (three); (copper alloy ?)	Seabed	34104
677.	METAL FRAGMENT	Metal piece	Seabed	29287
678.	METAL FRAGMENT	Metal rod in wood fragment	Seabed	33872
679.	PAPER FRAGMENT	Paper fragments	Easton trunk	29087
680.	PAPER FRAGMENT	Paper fragments; white	Easton trunk	29234
681.	PAPER FRAGMENT	Paper fragments and sediment	Easton trunk	29236
682.	PAPER FRAGMENT	Paper fragments	Easton trunk	29283
683.	PAPER FRAGMENT	Paper fragments (five); elliptical	Easton trunk (L-3)	29309
684.	PAPER FRAGMENT	Paper (?) fragment; brittle	Seabed	29339
685.	PAPER FRAGMENT	Small paper fragment	Dement trunk	33786
686.	PAPER FRAGMENT	Square paper fragment; small	Dement trunk	33787
687.	PAPER FRAGMENT	Paper (?) fragment	Seabed	34098
688.	PAPER FRAGMENT	Paper square	Seabed	34059
689.	PAPER FRAGMENT	Paper strips	Dement trunk	34042
690.	RUBBER FRAGMENT	Miscellaneous rubber fragments	Dement trunk	33894
691.	RUBBER FRAGMENT	Rubber fragment	Seabed	33870
692.	RUBBER FRAGMENT	Rubber piece with eye	Seabed	33856
693.	UNIDENTIFIED FRAGMENT	Circular fragments (two); soft	Seabed	33926
694.	UNIDENTIFIED FRAGMENT	Fragile fragment; square	Dement trunk	33903
695.	UNIDENTIFIED FRAGMENT	Fragile fragments (two); black	Dement trunk	33906
696.	UNIDENTIFIED FRAGMENT	Solid fragments (two)	Dement trunk	33905
697.	UNIDENTIFIED FRAGMENT	Unidentified fragments (multiple pieces); fibrous; fragile	Seabed	29337
698.	UNIDENTIFIED FRAGMENT	White fragment with holes; calcified	Seabed	33940
699.	WICKER FRAGMENT	Wicker fragment	Seabed	34094
700.	WOOD, WORKED	Wood cylinder fragments	Seabed	34027
701.	WOOD, WORKED	Wood fragment	Seabed	19002
702.	WOOD, WORKED	Wood fragment	Seabed	19003
703.	WOOD, WORKED	Wood fragment; thin slab	Seabed	29336
704.	WOOD, WORKED	Wood fragment	Dement trunk	33889
705.	WOOD, WORKED	Wood fragment	Seabed	33910
706.	WOOD, WORKED	Wood fragment with screw	Seabed	33913
707.	WOOD, WORKED	Wood fragment	Seabed	33941
708.	WOOD, WORKED	Wood fragment	Seabed	33956
709.	WOOD, WORKED	Wood fragment	Seabed	33961
710.	WOOD, WORKED	Wood fragment	Seabed	33962
711.	WOOD, WORKED	Wood fragment	Seabed	33983
712.	WOOD, WORKED	Wood fragment with metal spikes	Seabed	34071
713.	WOOD, WORKED	Wood fragment	Seabed	34072
714.	WOOD, WORKED	Wood fragment	Seabed	34073
715.	WOOD, WORKED	Wood fragment	Seabed	34083
716.	WOOD, WORKED	Wood fragment; 64 cm long, 4 cm wide, and 1 cm thick; square nail holes (?); copper alloy staining	Seabed	34100
717.	WOOD, WORKED	Wood fragment	Seabed	29334
718.	WOOD, WORKED	Wood fragments	Seabed	33874
719.	WOOD, WORKED	Wood fragments	Seabed	34080
720.	WOOD, WORKED	Wood (box ?) fragments; two pieces; numerous wood-borer holes	Seabed	34099
721.	WOOD, WORKED	Wood with gold dust	Seabed	31398
	Class: Function Unknown – artifacts created to serve unknown purposes			
722.	UNIDENTIFIED OBJECT	Carved wooden object	Seabed	33848
723.	UNIDENTIFIED OBJECT	Carved wooden object	Seabed	33849
724.	UNIDENTIFIED OBJECT	Glass rectangle	Seabed	33969
725.	UNIDENTIFIED OBJECT	Hexagonal flower-shaped object; 7.9 cm; fabric; stuffed	Dement trunk	33759
726.	UNIDENTIFIED OBJECT	Long, box like object	Dement trunk	33756
727.	UNIDENTIFIED OBJECT	Metal cylinder	Seabed	33854

Appendix C (Continued)

Ref No.	Object	Description	Site Location	Artifact No.
728.	UNIDENTIFIED OBJECT	Metal object	Seabed	29257
729.	UNIDENTIFIED OBJECT	Metal object, five petals (tulip shaped); petals folded; 0.4 cm	Easton trunk	29310
730.	UNIDENTIFIED OBJECT	Metal ring	Seabed	33953
731.	UNIDENTIFIED OBJECT	Metal ring	Seabed	33984
732.	UNIDENTIFIED OBJECT	Metal ring	Seabed	33985
733.	UNIDENTIFIED OBJECT	Metal ringed object	Seabed	33853
734.	UNIDENTIFIED OBJECT	Rectangle	Seabed	29319
735.	UNIDENTIFIED OBJECT	Sludge; black; found in corner of trunk	Dement trunk	33902
736.	UNIDENTIFIED OBJECT	Spherical (three) seed pods (?); brown	Dement trunk	33744
737.	UNIDENTIFIED OBJECT	Spherical; brown; seed pod (?)	Dement trunk	33808
738.	UNIDENTIFIED OBJECT	Spherical; brown; animal excrement (?); found with shirt (see No. 33745)	Dement trunk	33747
739.	UNIDENTIFIED OBJECT	Spherical; brown; seed pod (?); found inside shirt (see No. 33745)	Dement trunk	33748
740.	UNIDENTIFIED OBJECT	Spherical; brown; seed pod (?); found inside shirt (see No. 33745)	Dement trunk	33749
741.	UNIDENTIFIED OBJECT	Gold rod; small	Seabed	31396
742.	UNIDENTIFIED OBJECT	Metal rings; small	Seabed	29293
743.	UNIDENTIFIED OBJECT	Wood piece; small; oval	Dement trunk	33794
744.	UNIDENTIFIED OBJECT	Solid object (leather ?)	Easton trunk (L-4)	29116
745.	UNIDENTIFIED OBJECT	Strand	Seabed	33930
746.	UNIDENTIFIED OBJECT	Thin metal ring and wire	Seabed	29292
747.	UNIDENTIFIED OBJECT	Two oval pieces, one wood and one paper	Dement trunk	33797
Class: Multiple Use Artifacts – artifacts created to serve a variety of purposes that extend beyond the range of one classification				
748.	BRUSH	Brush part	Seabed	33935
749.	CLOTH	Fabric or paper wrapped around package	Easton trunk (L-4)	29112
750.	CLOTH	Fabric wrapped around jar (see No. 29203)	Easton trunk (L-6)	29172
751.	CLOTH	Fabric wrapped around box with ambrotype and note (see Nos. 29126, 29209, 29210)	Easton trunk (L-4)	29232
752.	HOOK	C-shaped hook; ring at one end; 3.1 cm length, 1.7 cm width	Seabed	34013
753.	STRING	String	Easton trunk (L-4)	29113
754.	TWINE	Twine, two pieces	Easton trunk	29231
755.	TWINE	Twine; found tied around cravat (see No. 29105)	Easton trunk (L-3)	29303
756.	TWINE	Twine; found tied around cravat (see No. 29104)	Easton trunk (L-3)	29304
757.	TWINE	Twine; found tied around cravat (see No. 29107)	Easton trunk (L-3)	29305
758.	TWINE	Twine; found tied around necktie (see No. 29100)	Easton trunk (L-3)	29300
759.	TWINE	Twine; found tied around necktie (see No. 29102)	Easton trunk (L-3)	29301
760.	TWINE	Twine; found tied around necktie (see No. 29099)	Easton trunk (L-3)	29302
761.	TWINE	Twine; found tied around necktie (see No. 29101)	Easton trunk (L-3)	29306
762.	TWINE	Twine; found tied around necktie (see No. 29106)	Easton trunk (L-3)	29307
CATEGORY 11: NATURAL ARTIFACTS – artifacts created by natural processes				
Class: Biological Object – artifacts created by biological processes				
763.	FEATHER	Feather	Dement trunk	33772
764.	FEATHER	Feather	Dement trunk	33795
765.	FIBERS	Fibrous mass with pteropods	Seabed	33937
766.	HAIR	Hair	Easton trunk	29321
767.	HAIR	Hair	Dement trunk	33907
768.	PLANT	Plant fibers [BR-157]	Seabed	34089
Class: Mineral Object – artifacts created by geological processes				
769.	COAL	Boiler coal, anthracite (one lump); small (4 cm)	Easton trunk	29230
770.	COAL	Boiler coal, anthracite (44 lumps)	Seabed	33887
771.	COAL	Boiler coal, anthracite (eight lumps) [BR-163, 166, 224, 225, 231, 256, 329, 330]	Seabed	19008
772.	GOLD DUST	Gold dust and small nuggets embedded in a thin layer of rust crust on wood fragment	Seabed	30140
773.	GOLD DUST	Gold dust and flakes	Seabed	Multiple
774.	GOLD NUGGET	Gold and quartz nugget	Seabed	31873
775.	GOLD NUGGET	Gold nugget; Africa-shaped	Seabed	31451
776.	GOLD NUGGET	Gold nuggets	Seabed	Multiple
777.	GOLD SPHERE	Gold alloy balls; amalgamation product (?); diameter range: 1 to 2 cm	Seabed	Multiple

Notes: Nomenclature based on Blackaby and Greeno (1988), *The Revised Nomenclature for Museum Cataloging*, which is a revised and expanded version of Robert G. Chenhall's system of classifying man-made objects.

Artifacts in this appendix are generally arranged in the following order: category, class (or subclass), object, description/location, and lastly artifact no.

L-1 to L-6 indicates layers of artifacts found in the Easton trunk; layer 1 (L-1) being the topmost layer of items in the trunk and layer 6 (L-6) being the bottommost layer.

BR-126 to BR-330 indicates cross-reference numbers for biological or geological specimens.

Artifacts located at the facilities of Columbus-America Discovery Group, Columbus, OH.